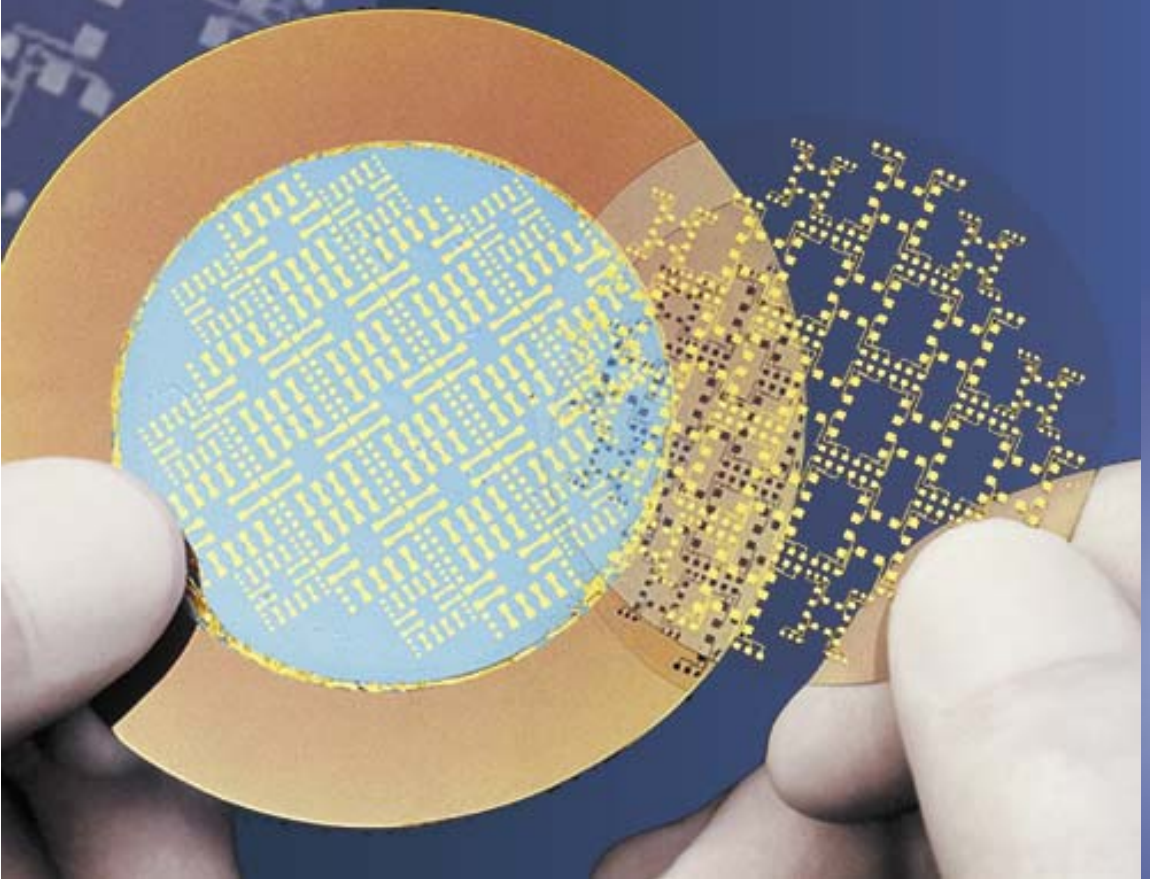
Nano-structured Thermoelectric Materials

8th Diesel Engine Emissions Reduction Conference

Loews Coronado Bay Resort

San Diego, CA

August 25, 2002



Rama Venkatasubramanian

RTI INTERNATIONAL

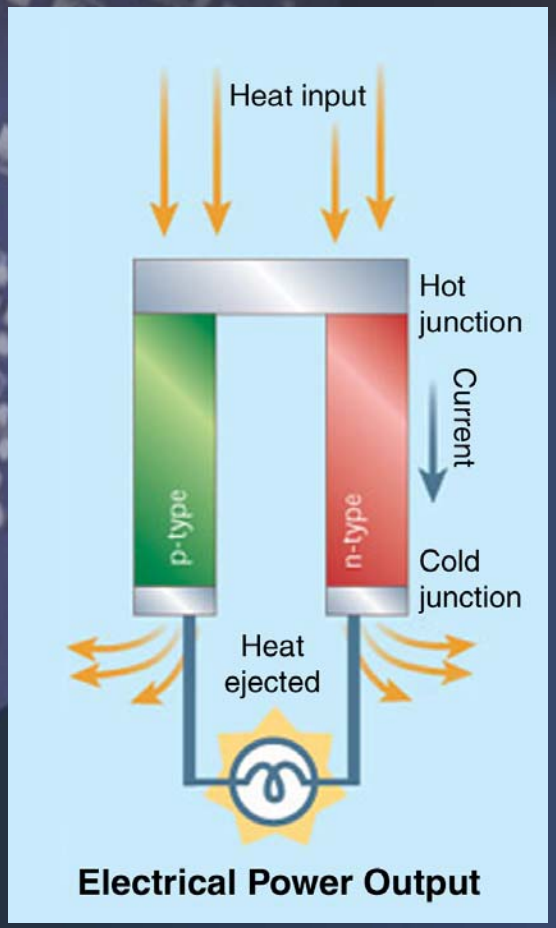
Outline

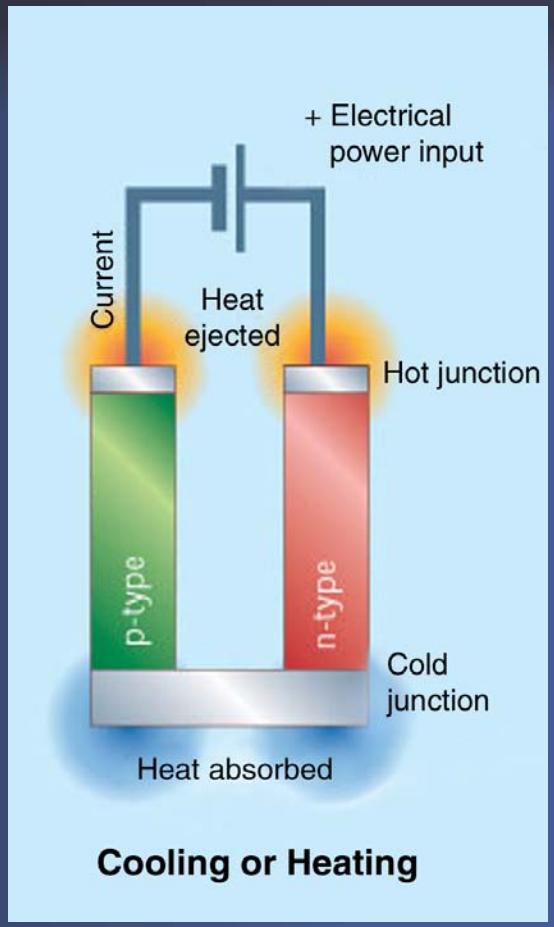
- Introduction – Relevance to CFC-free Air-conditioning in Automobiles, Energy Conservation and Emissions Reduction
- Advantages of Technology and Thin-film Cooling Examples
- Thin-film Power Conversion Examples
- Major Outstanding Issues for Research
- Emerging Thin-film TE Technology Applications

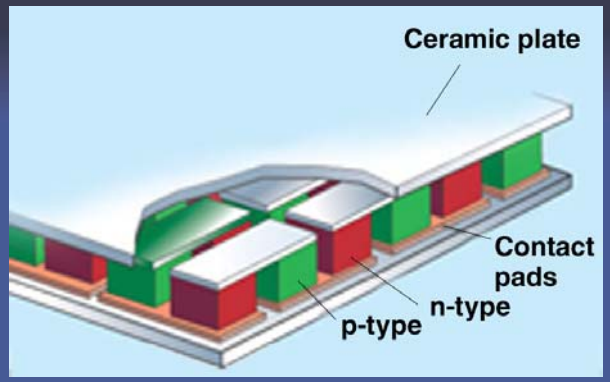
Why Thermoelectrics?

- Converts electrical and thermal energy using a solid state device with minimal moving parts
- **Chip-scale functionality** with thin-film materials using standard microelectronic processing
  - Computer Chip, Photonic Chip, Lab-on-a-Chip
- Green Technology – CFC-free refrigeration to waste-heat recovery for fuel efficiency

Thermoelectric Effect



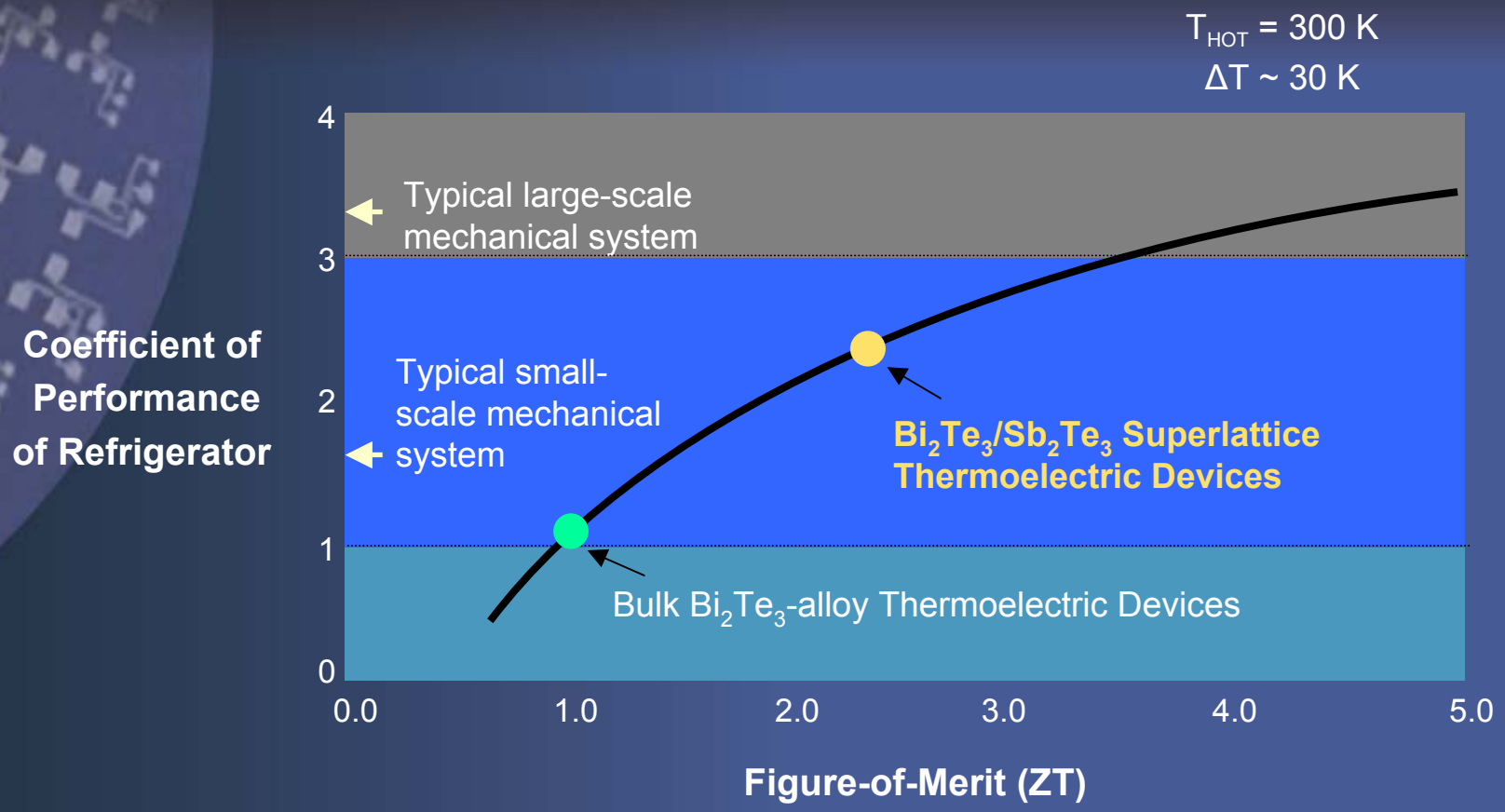




- Cooling or Power Conversion Efficiency critically dependent on the material Figure of Merit (ZT)
- $ZT = (\alpha^2\sigma/K)T$
- Minimize thermal conductivity and maximize electrical conductivity

Ref : Nature, 413, 577 (2001)

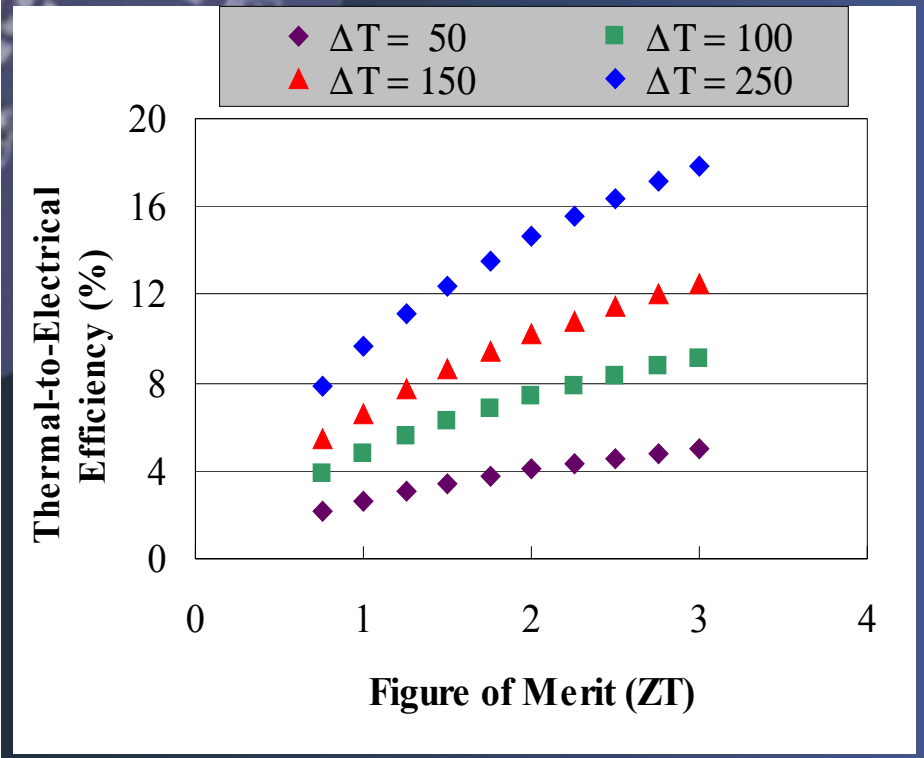
ZT and COP of Refrigerator or Air-Conditioner

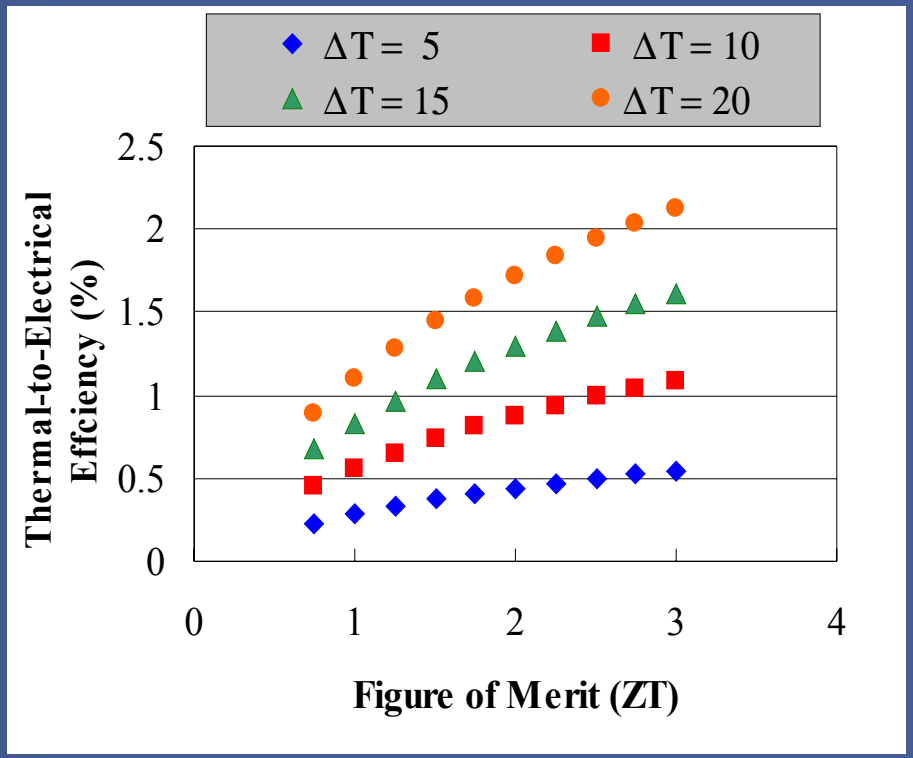


Higher ZT – Incentives for New Approaches to Implementing Higher COP Concepts

Implications for Power

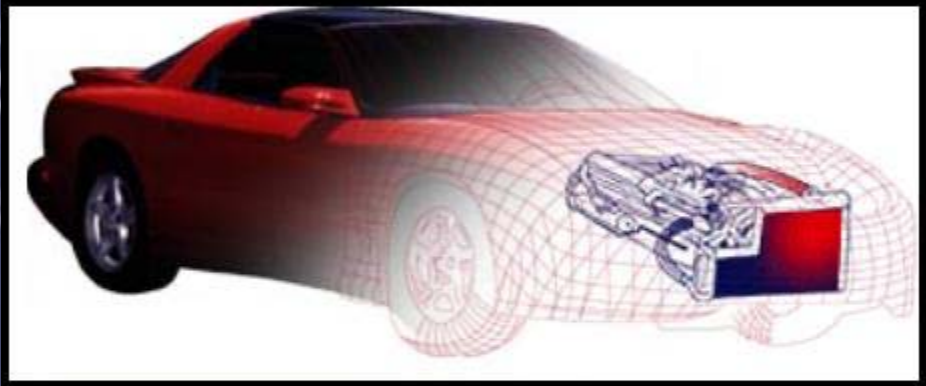
- High-density, light-weight
- Higher efficiency
- Replace Batteries



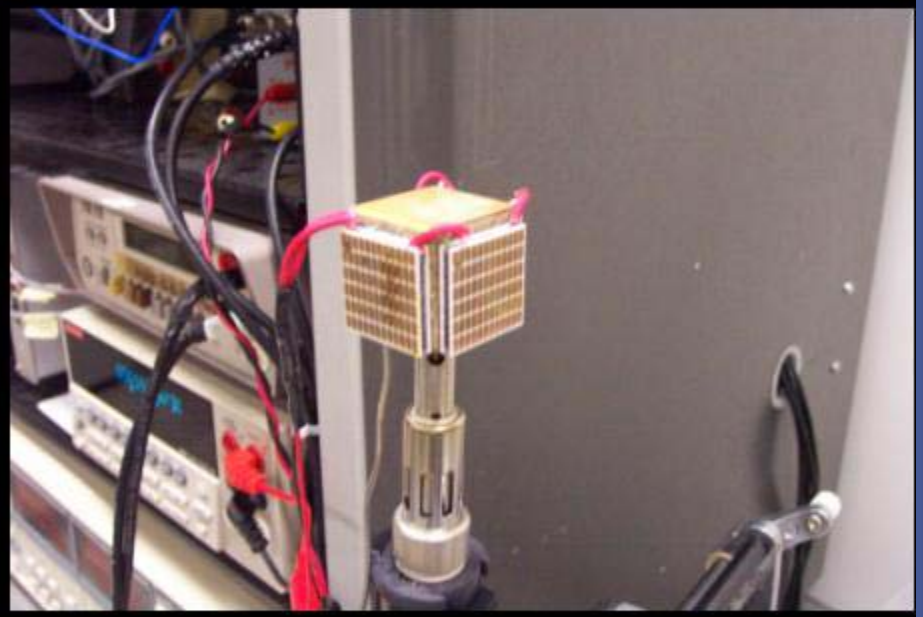


Automotive Power

Waste-heat recovery for electrical power

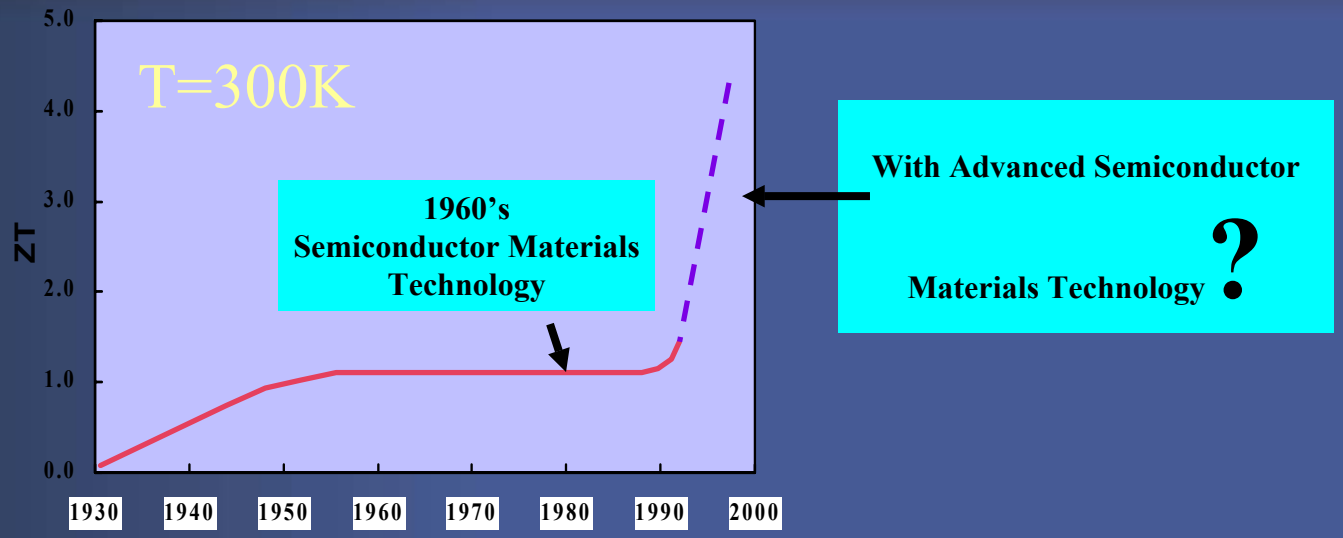


Portable power



Thermal scavenging for remote power

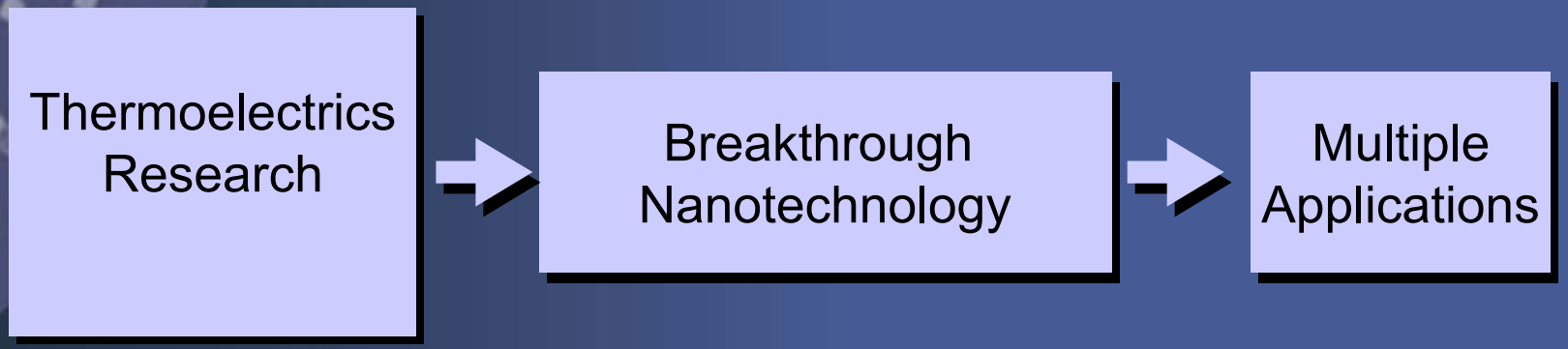
THERMOELECTRIC TECHNOLOGIES in 1992
Fort Belvoir Workshop Organized by Dr. Stuart Horn



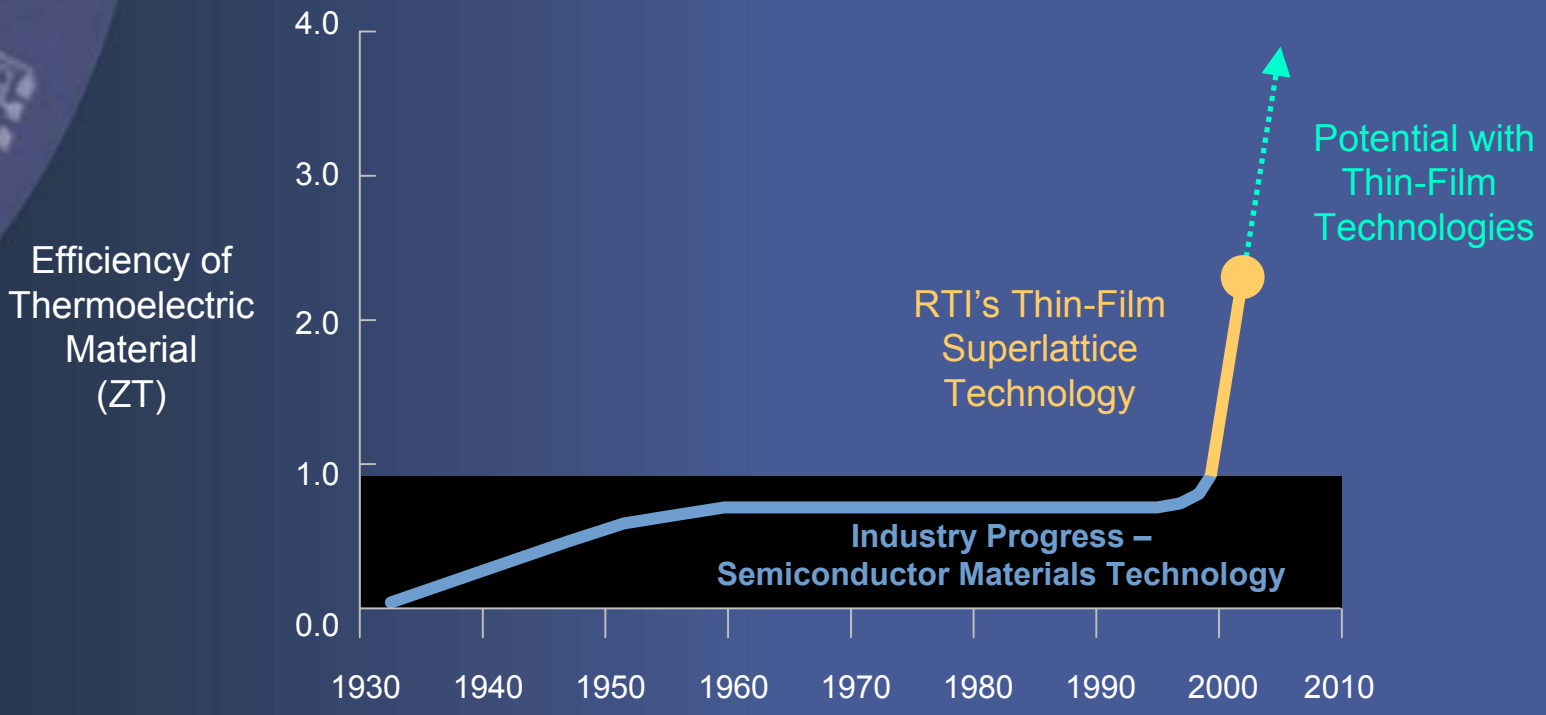
- ZT - figure of merit - has been stagnant at about 0.8 to 1 for the last 40 years - cooling and power conversion efficiencies low - useful only in applications where you <u>really need</u> it
- ZT need to improve over 1.5 at 300K for a major impact in electronics and around 2 to 2.5 for a revolutionary impact in air-conditioning, and power from waste-heat

Some of the Bulk Material and Thin-film Developments

- Cs Bi_4Te_6 (Michigan State University)
  - Bulk Materials with a ZT~ 0.8 at 225K but less than 0.8 at 300K (*Science* **287**, 1024-1027, 2000)
- Filled Skuterrudites (JPL)
  - Bulk materials with a ZT ~1.35 at 900K (Proc. Of 15th International Conf. On Thermoelectrics, 1996)
- PbTe/PbTeSe Quantum-dots (MIT Lincoln Labs.)
  - ZT~2 at 550K and ZT~0.8 at 300K based on estimated thermal conductivity values (J. Electronic Materials, 29, L1 , 2000)
- Bi_2Te_3/Sb_2Te_3 Superlattices (RTI)
  - ZT~2.4 at 300K in devices with all properties measured at the same place, same time, with current flowing and verified by two independent techniques (*Nature*, 597-602, 2001)


Thermoelectrics Research
Breakthrough Nanotechnology
Multiple Applications

RTI's 40-Year Breakthrough



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Cool new film

Metal sandwiches can pump heat rapidly to or from chips.

11 October 2001

PHILIP BALL

New composite could shrink thermoelectric coolers like this one to the size of a chip.
© Coolworks Inc.

A new composite could cool computer chips or warm scaled-down industrial chemical processing. It can pump heat rapidly to or from miniature devices.

The material, devised by Rama Venkatasubramanian and colleagues at the Research Triangle Institute in North Carolina[1], relies on both aspects of the thermoelectric effect. The first aspect is that current is generated in two electrically conducting materials in contact when one is hotter than the other. The

relatedstories

- **Holes plug leaky circuits** *24 July 2001*
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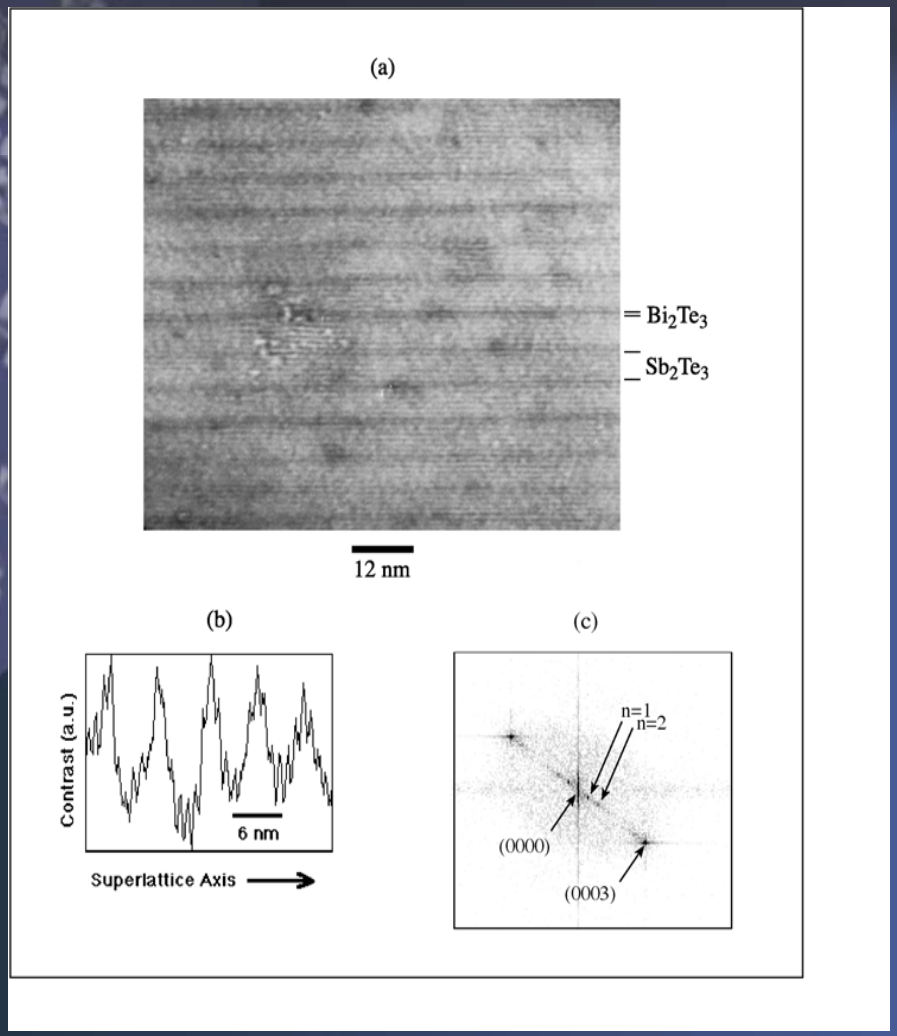
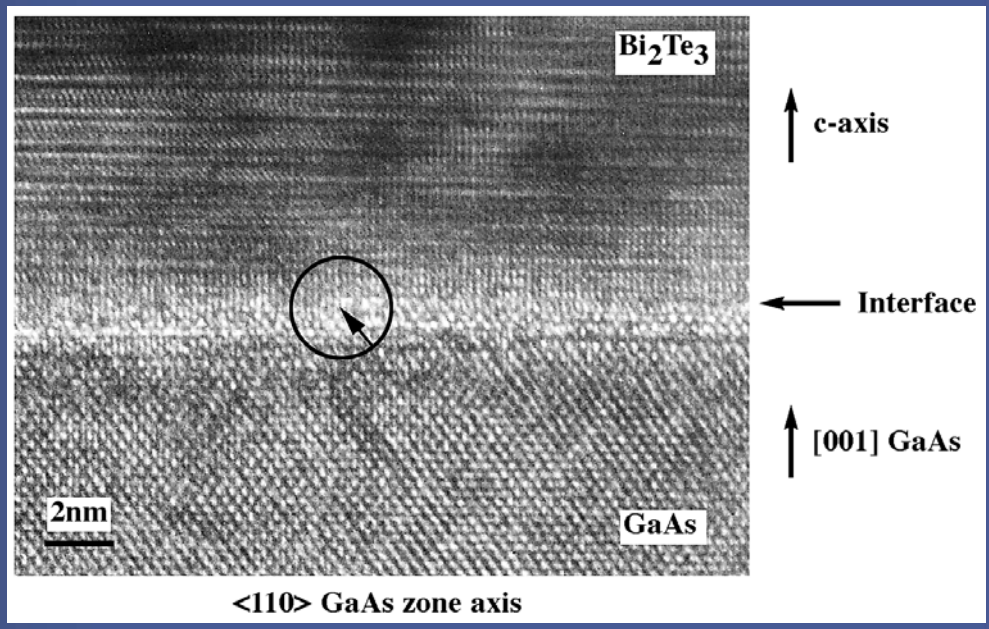
RTI's Nano-structured Superlattice Material



- 10Å/50Å Bi_2Te_3/Sb_2Te_3 Structure
- Optimized for disrupting heat transport while enhancing electron transport perpendicular to the superlattice interfaces

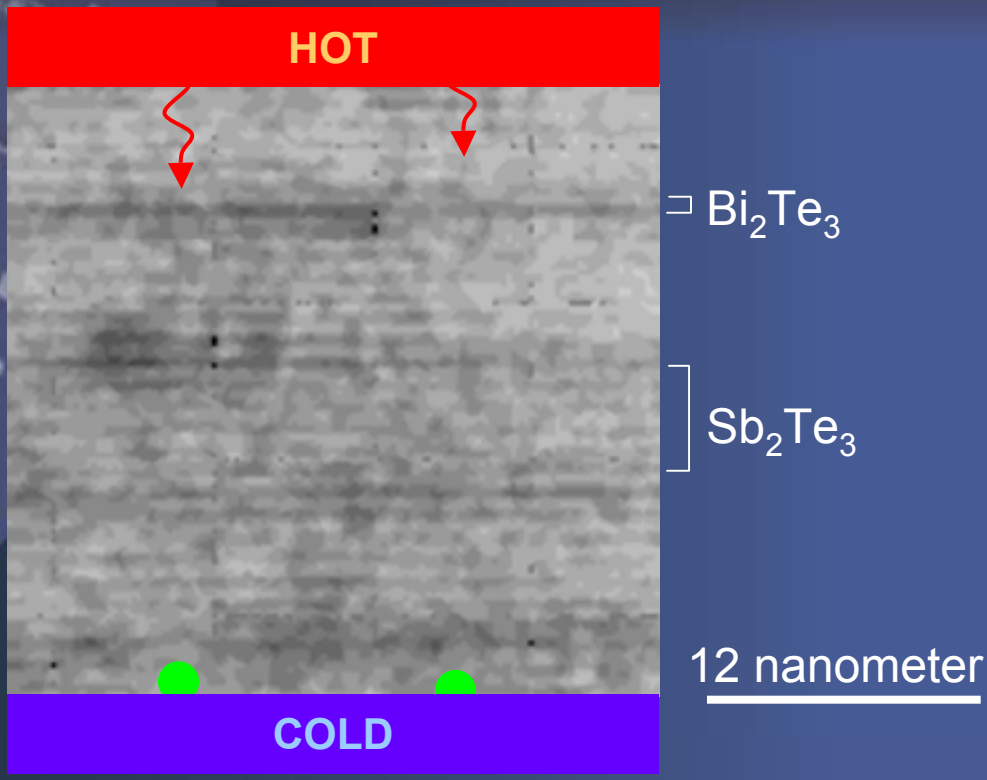
Applied Physics Letters, 75, 1104 (1999)

MOCVD Growth of Superlattices



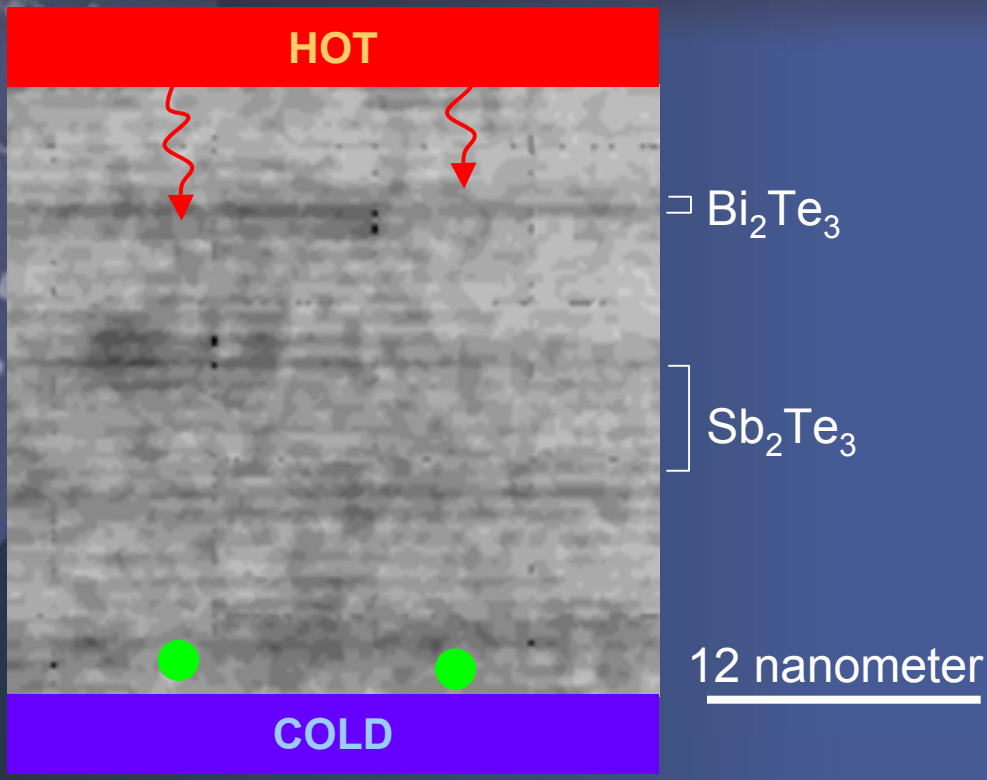
- Low-temperature technology and scaleable for large areas
- In-situ ellipsometry for nanometer-scale control of deposition

RTI's Superlattice Material



The RTI breakthrough arises from reducing heat transmission without disrupting electron flow

RTI's Superlattice Material



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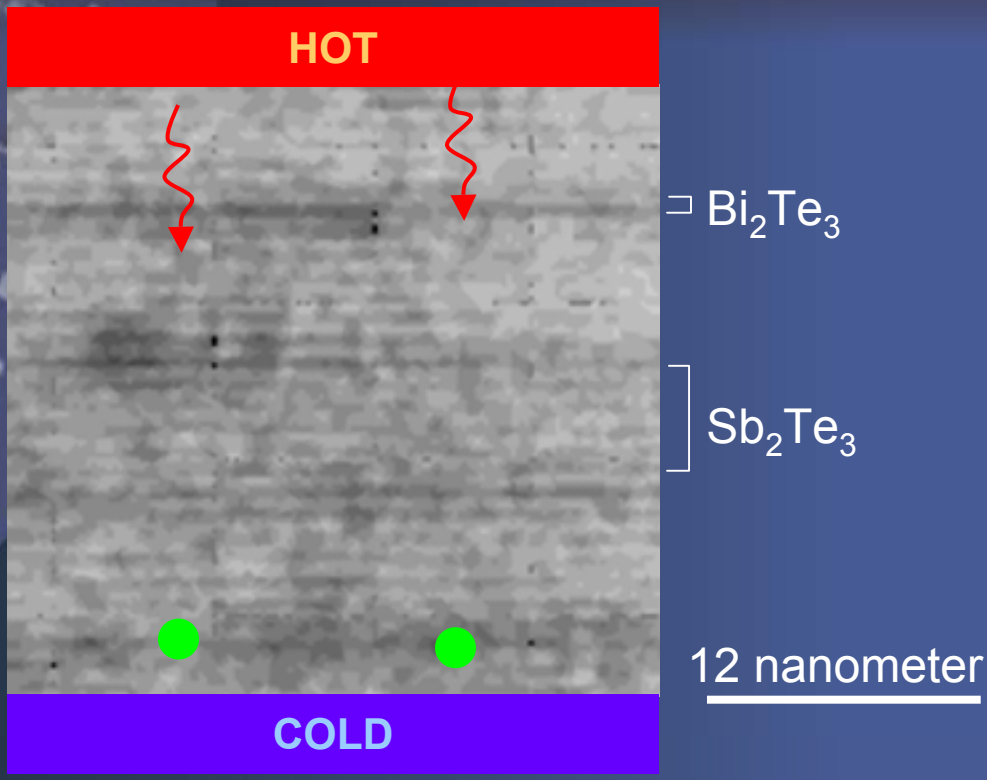

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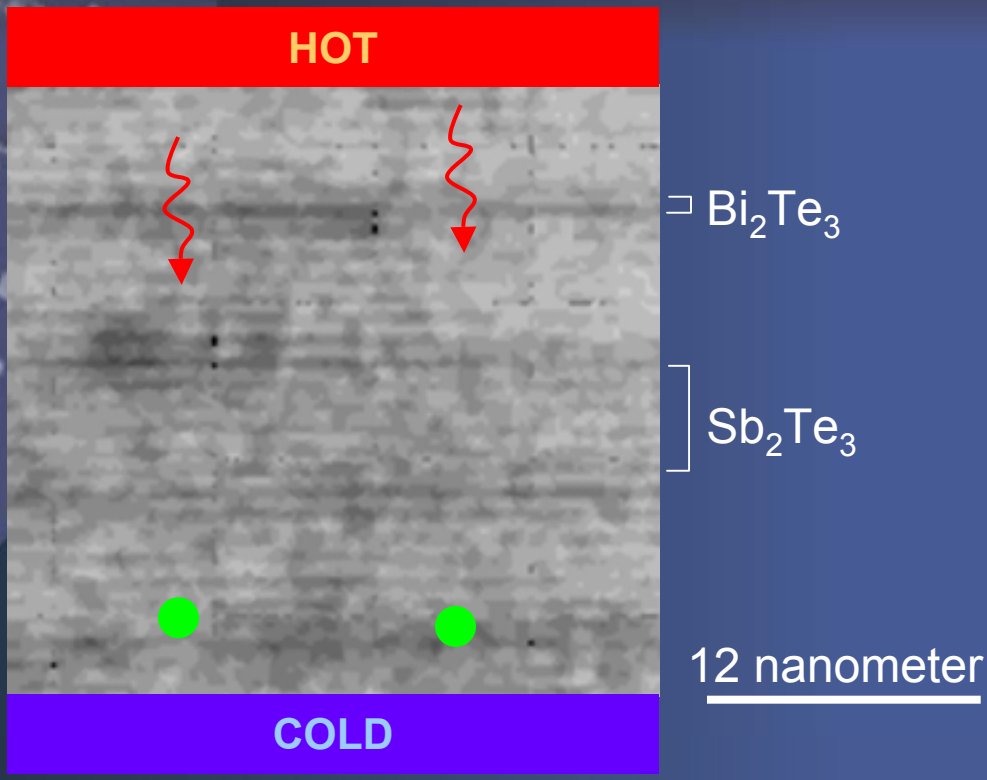

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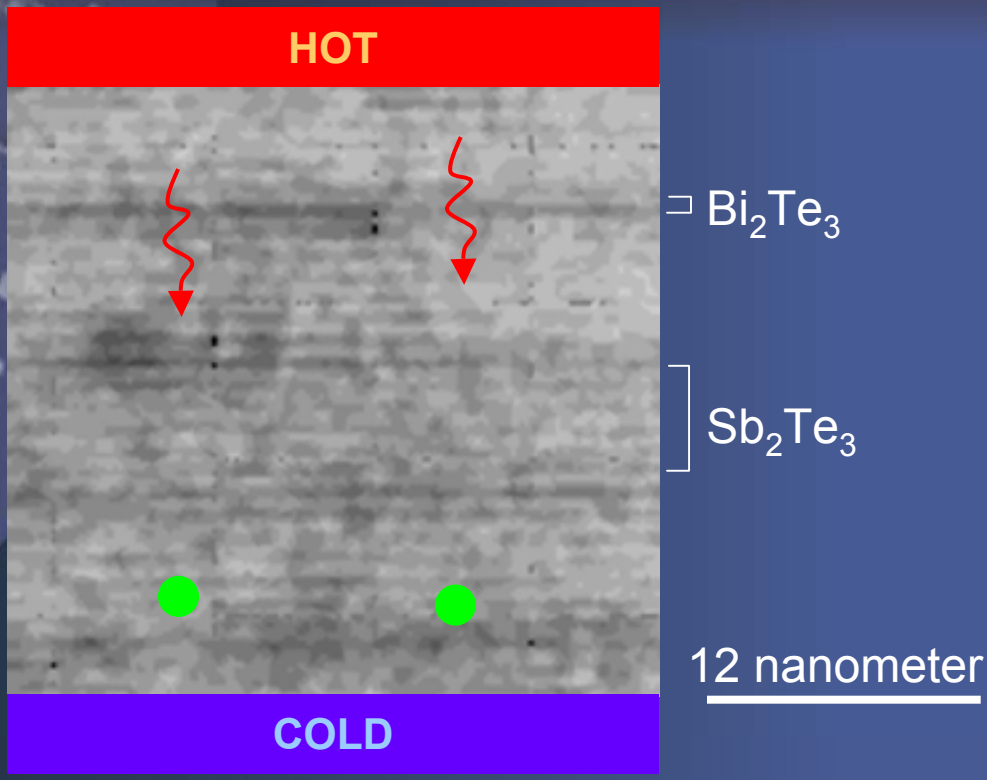

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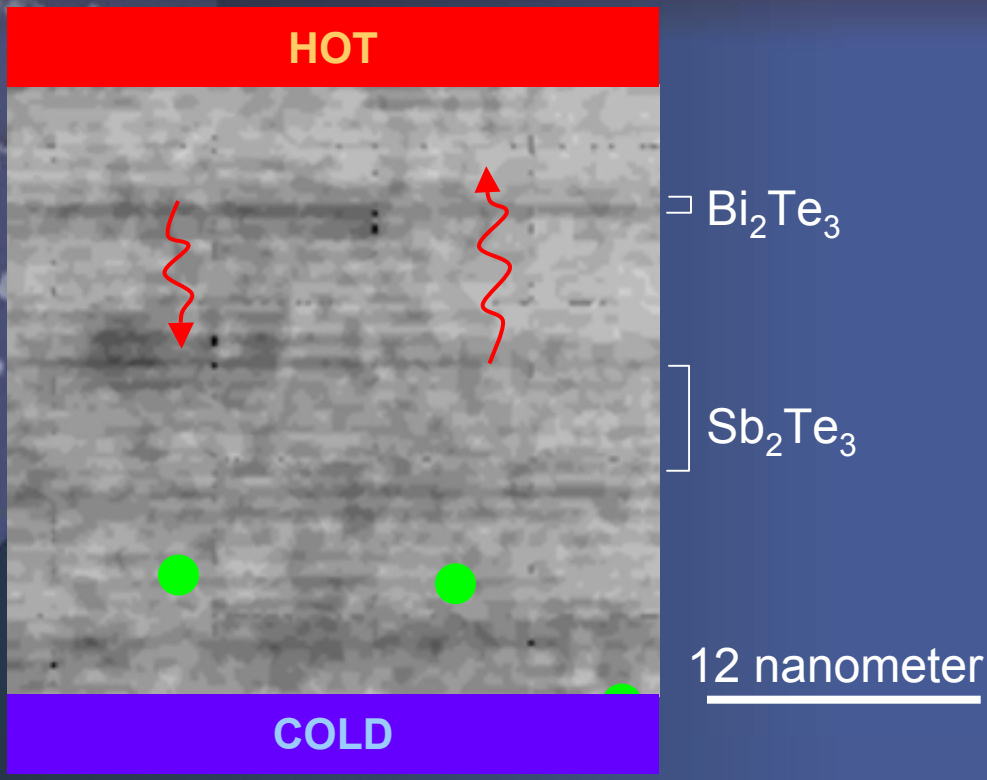

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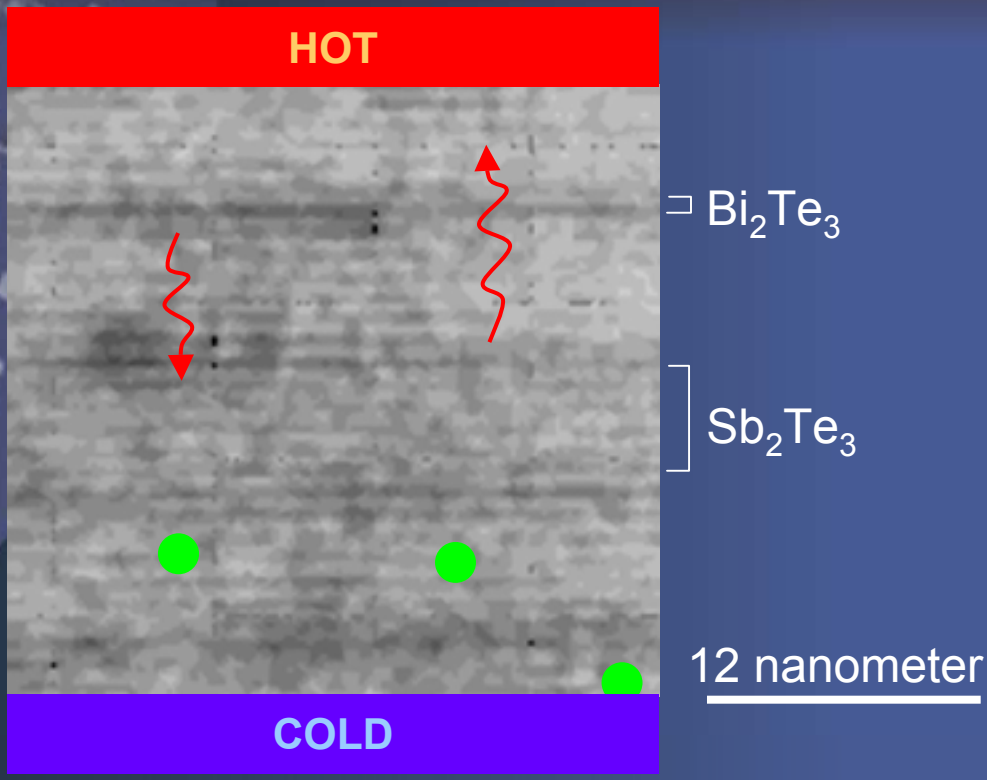

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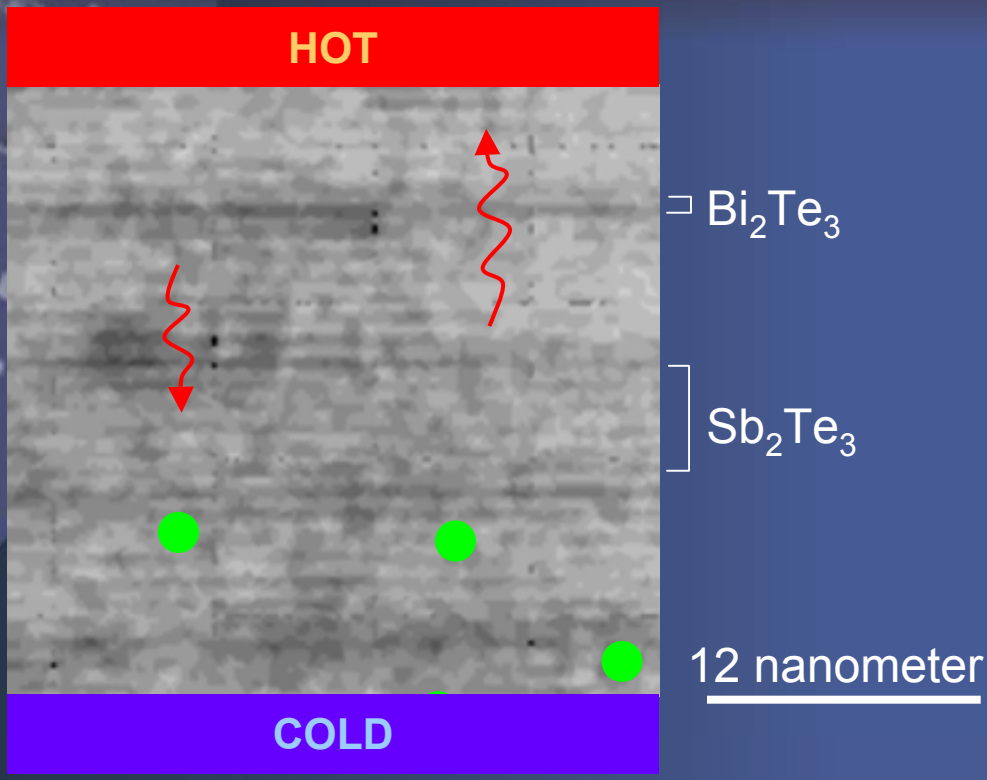

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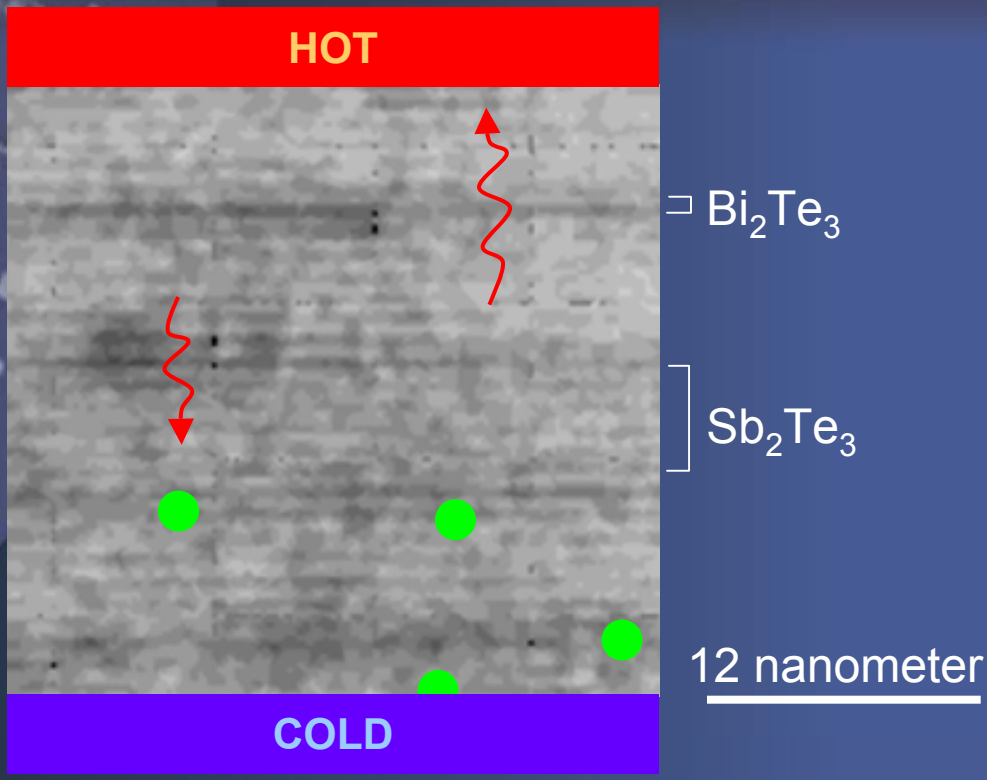

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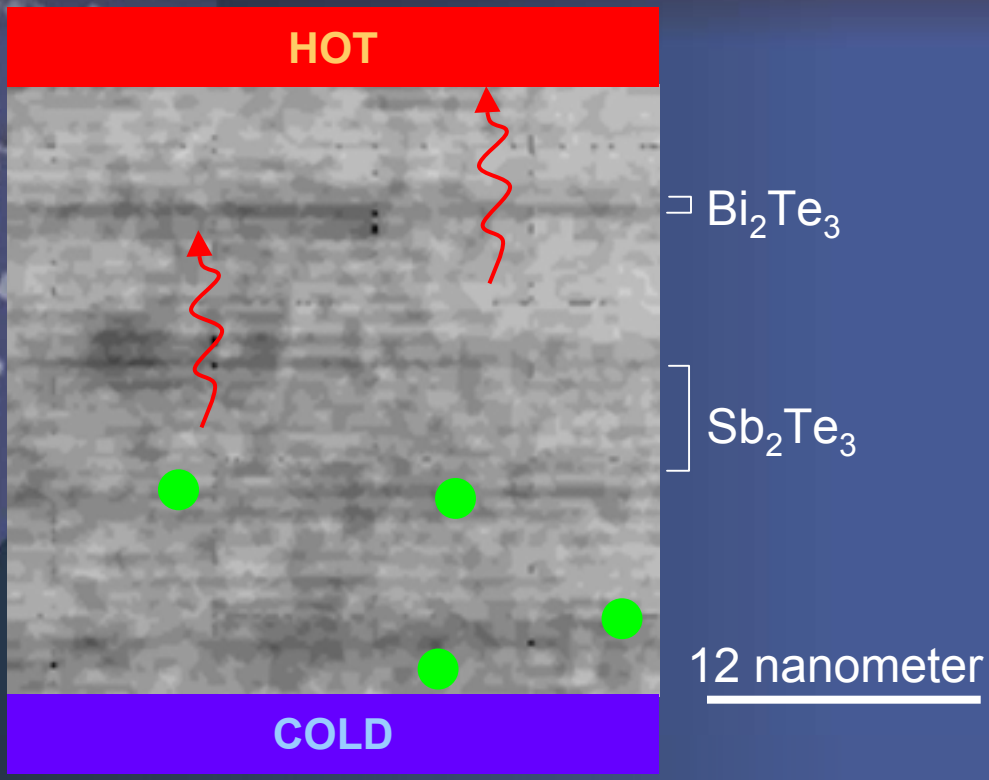

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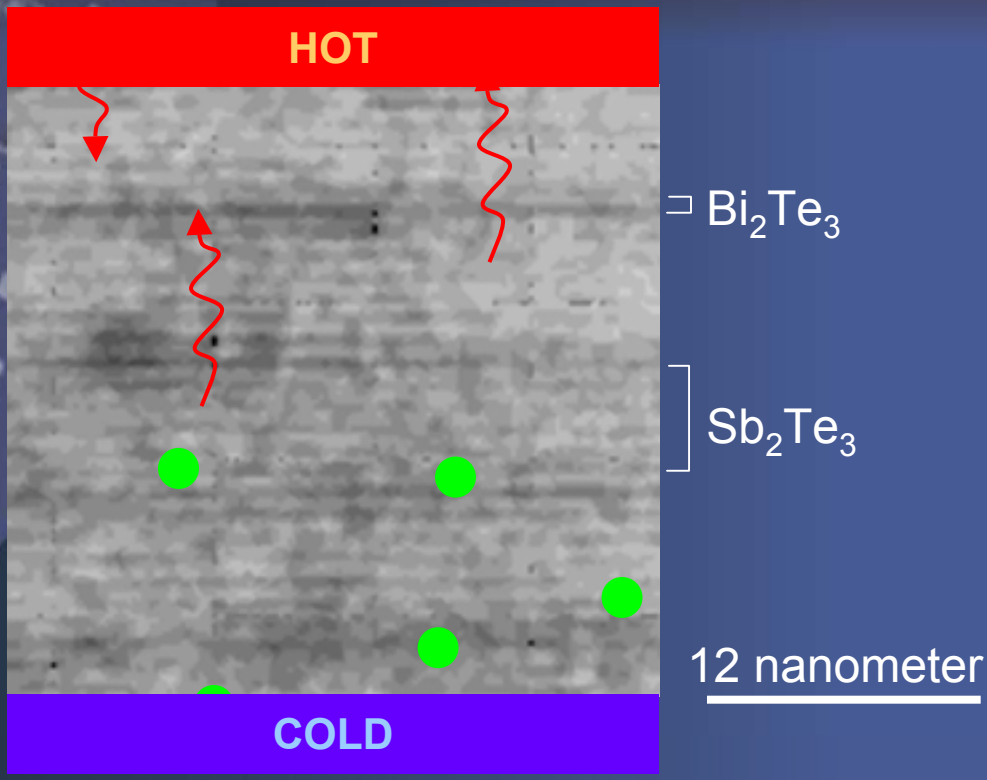

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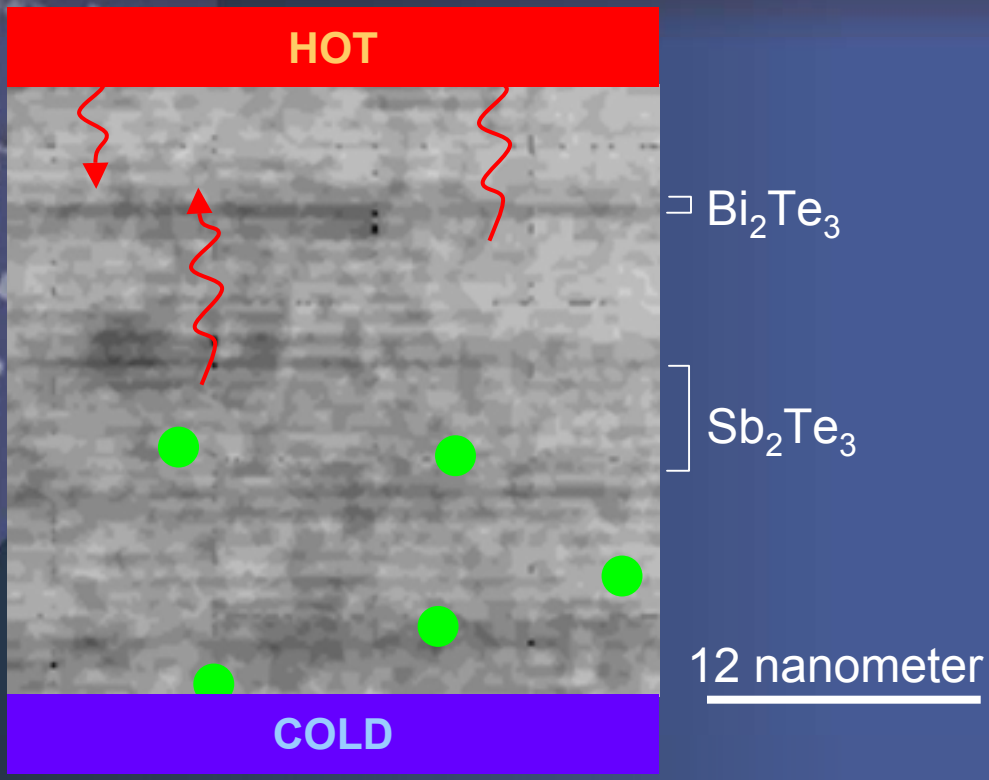

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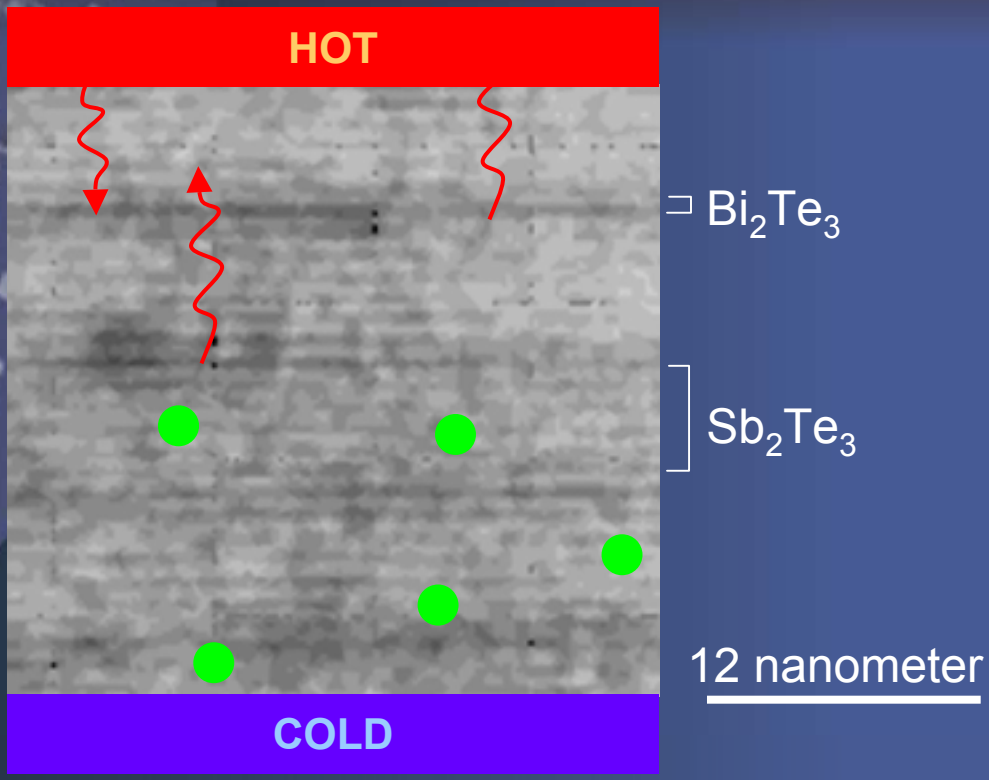

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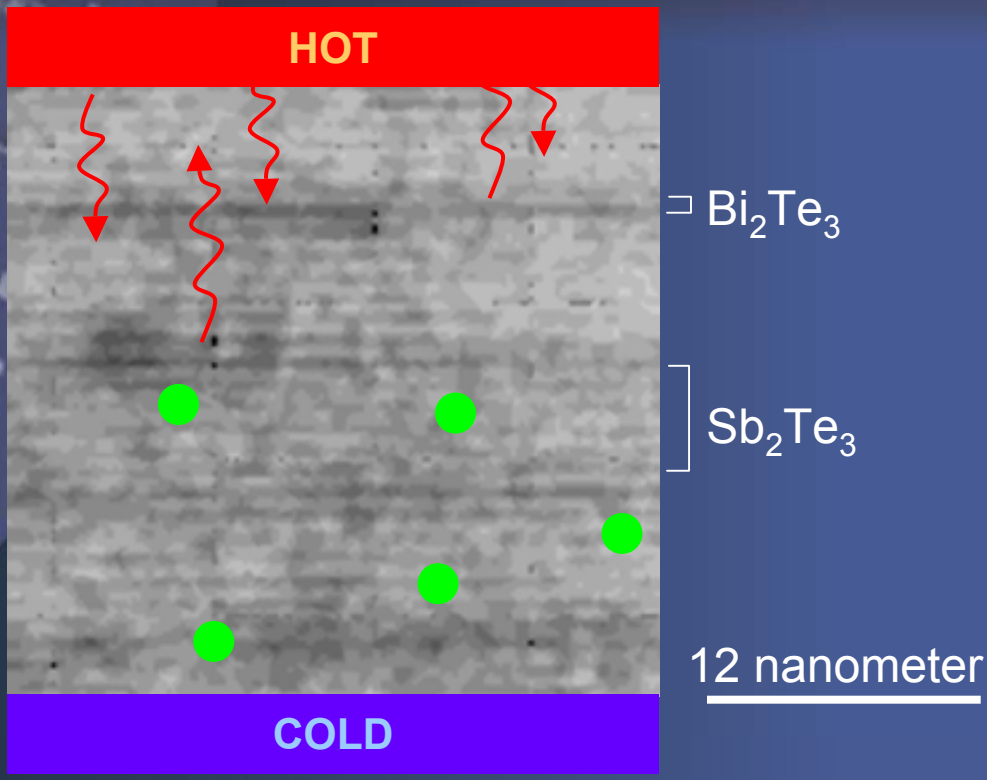

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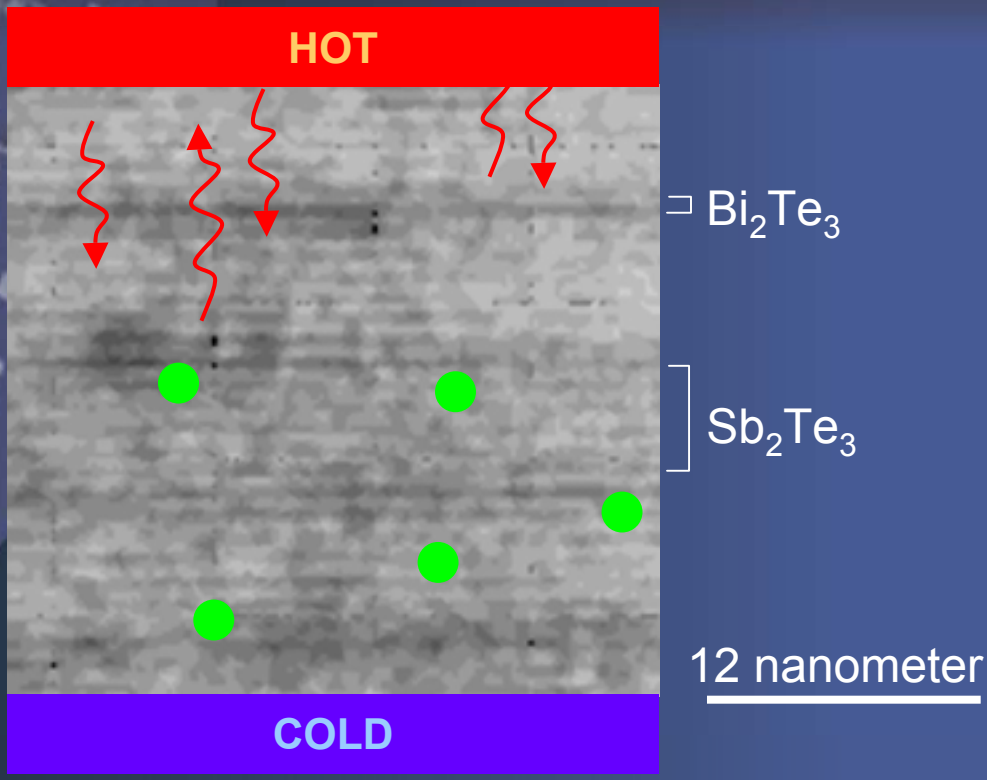

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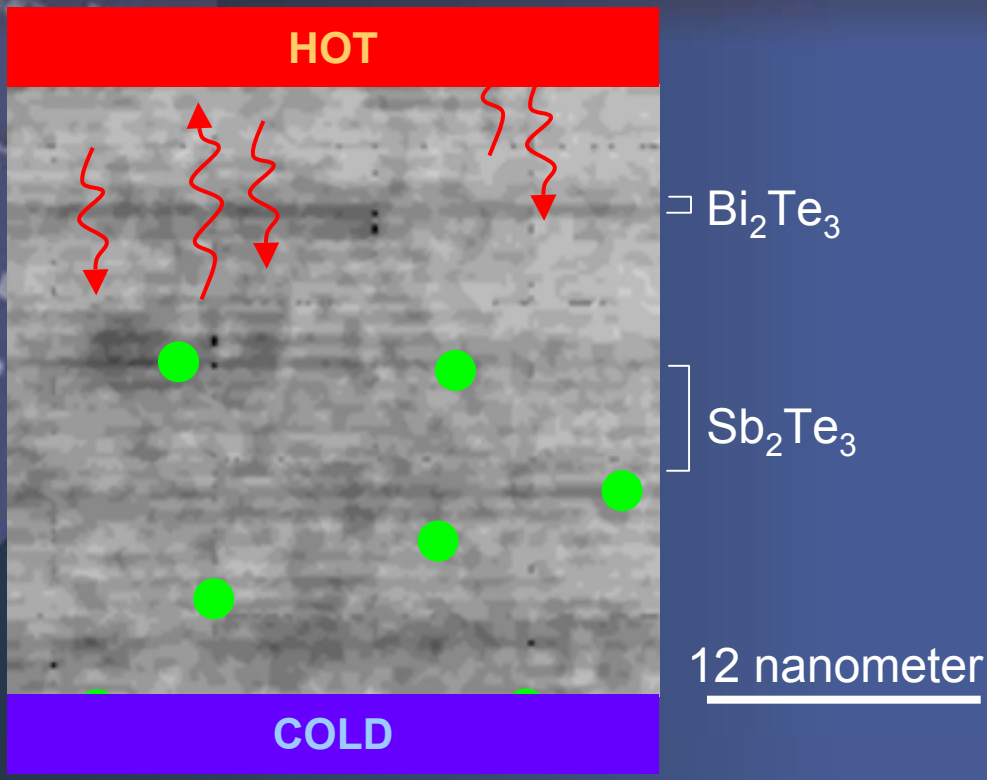

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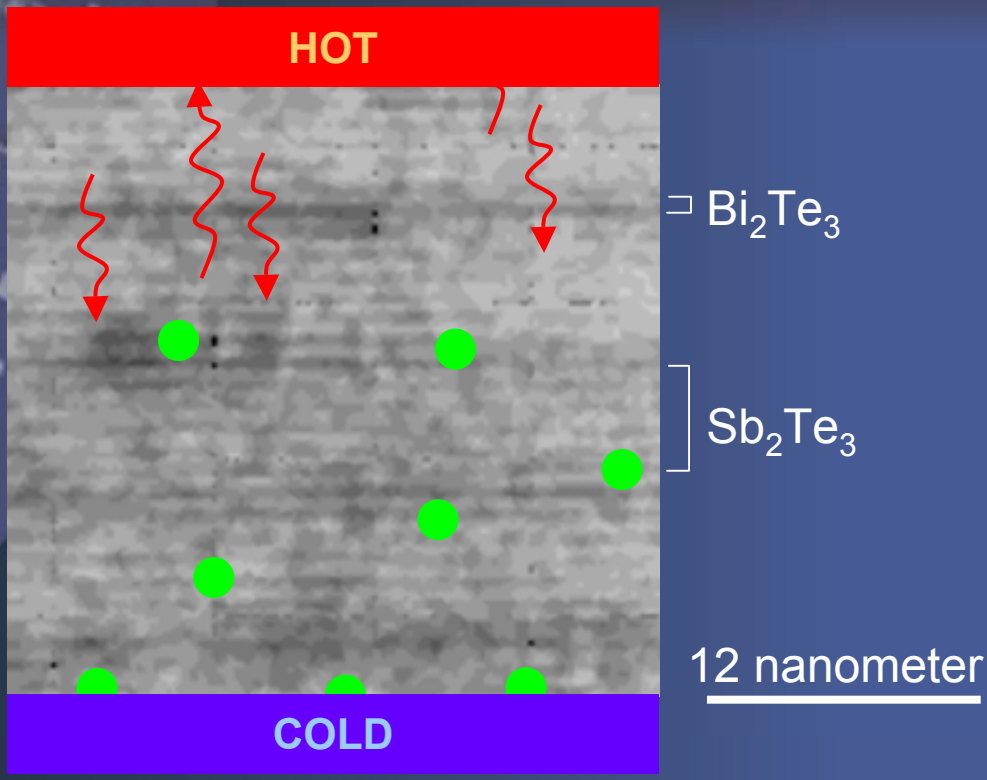

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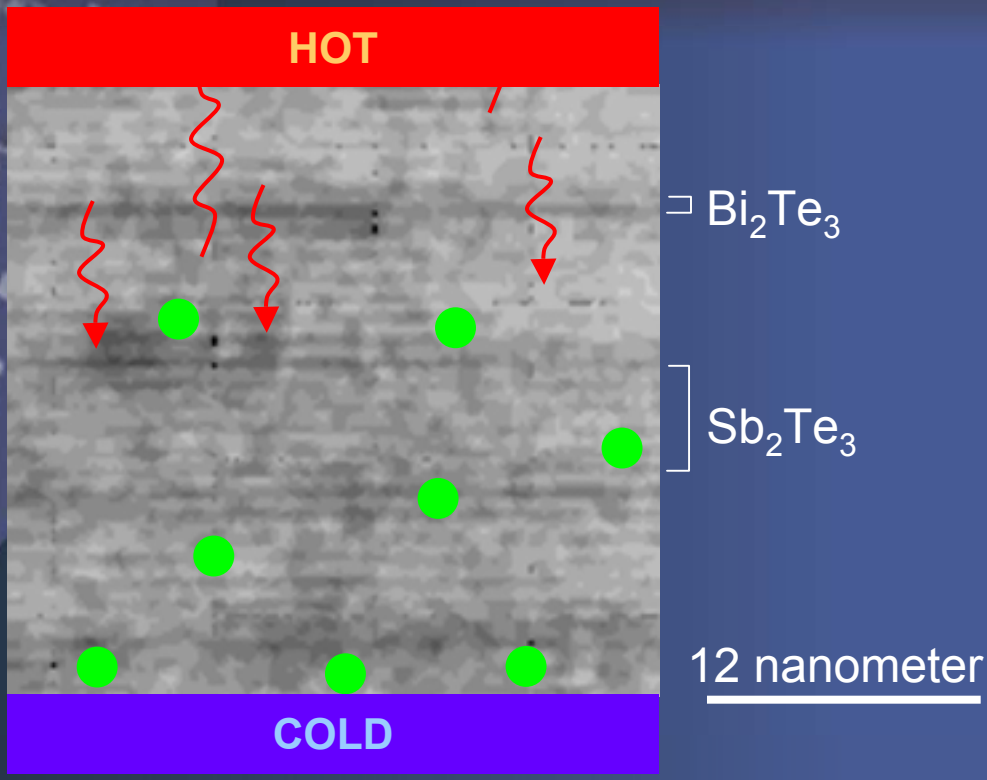

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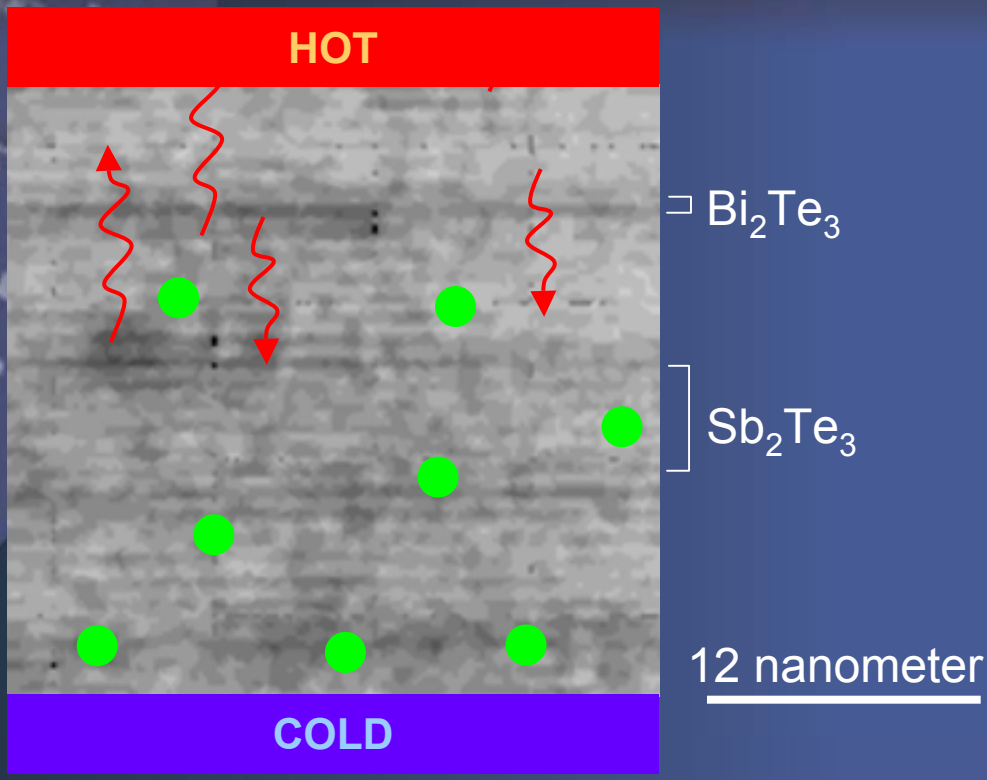

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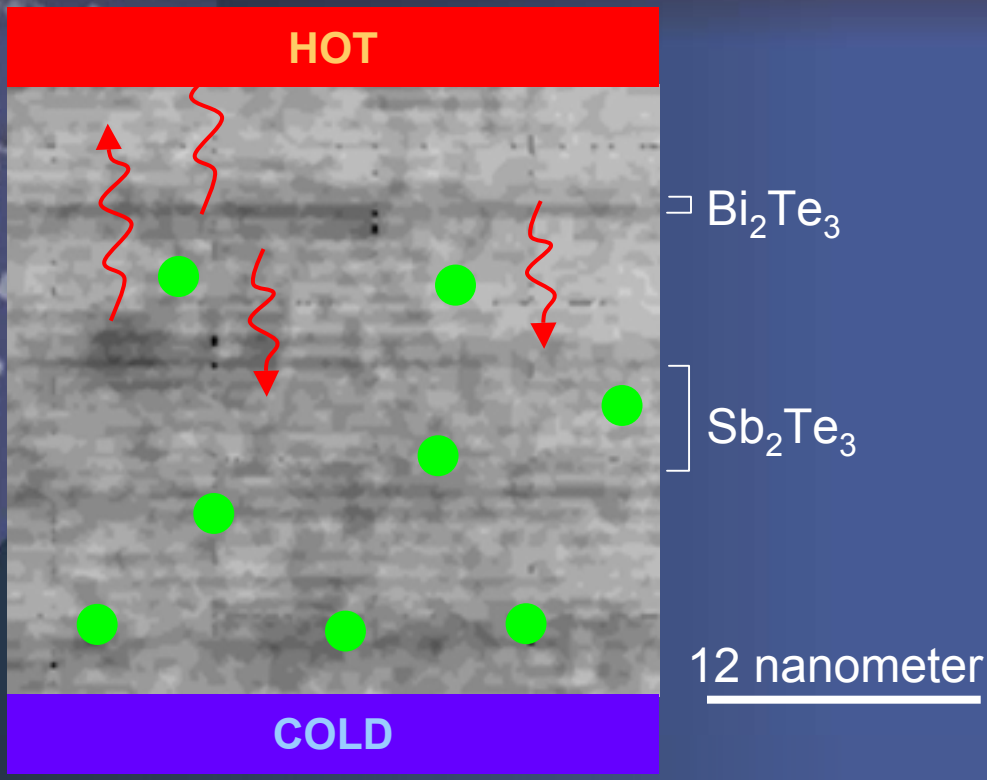

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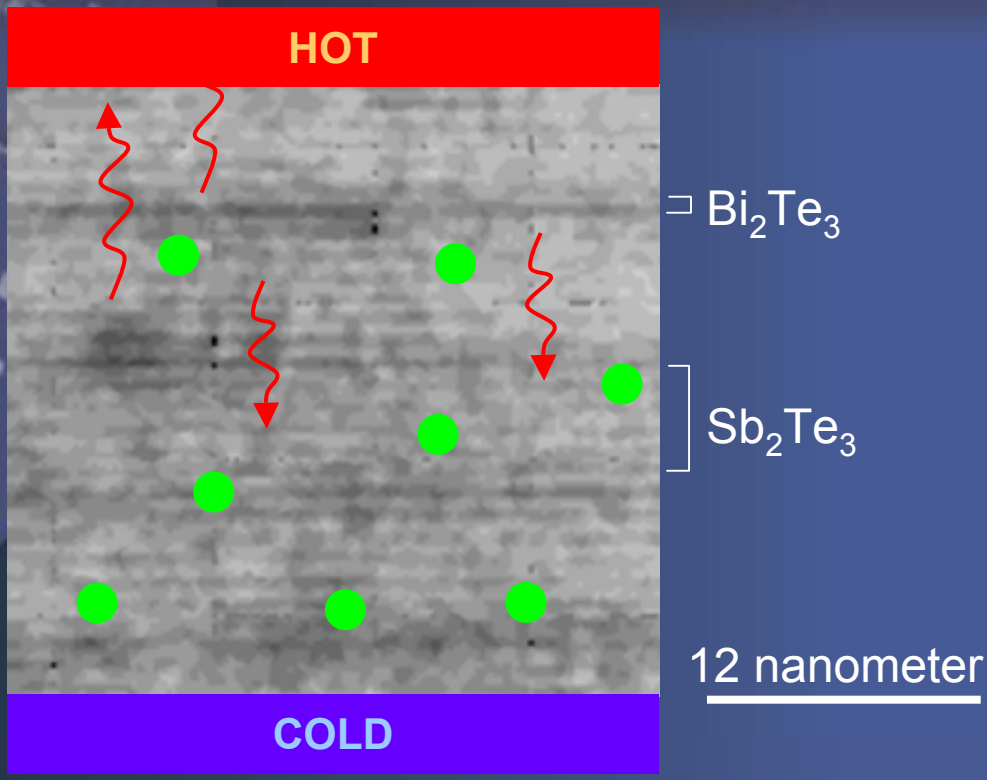

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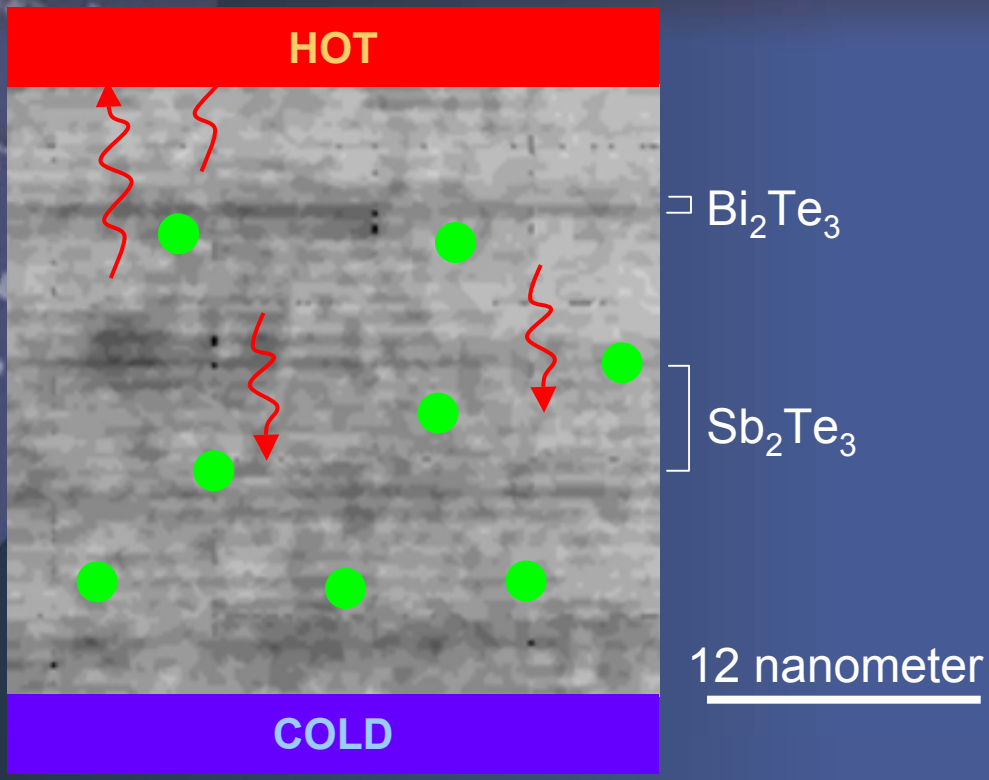

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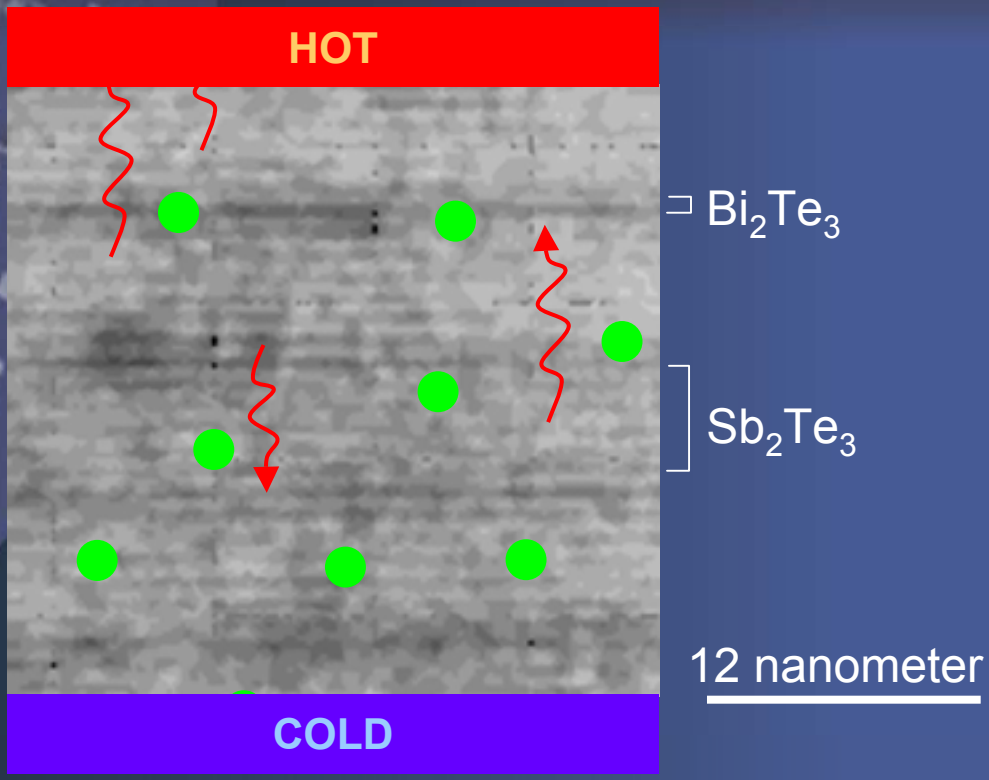

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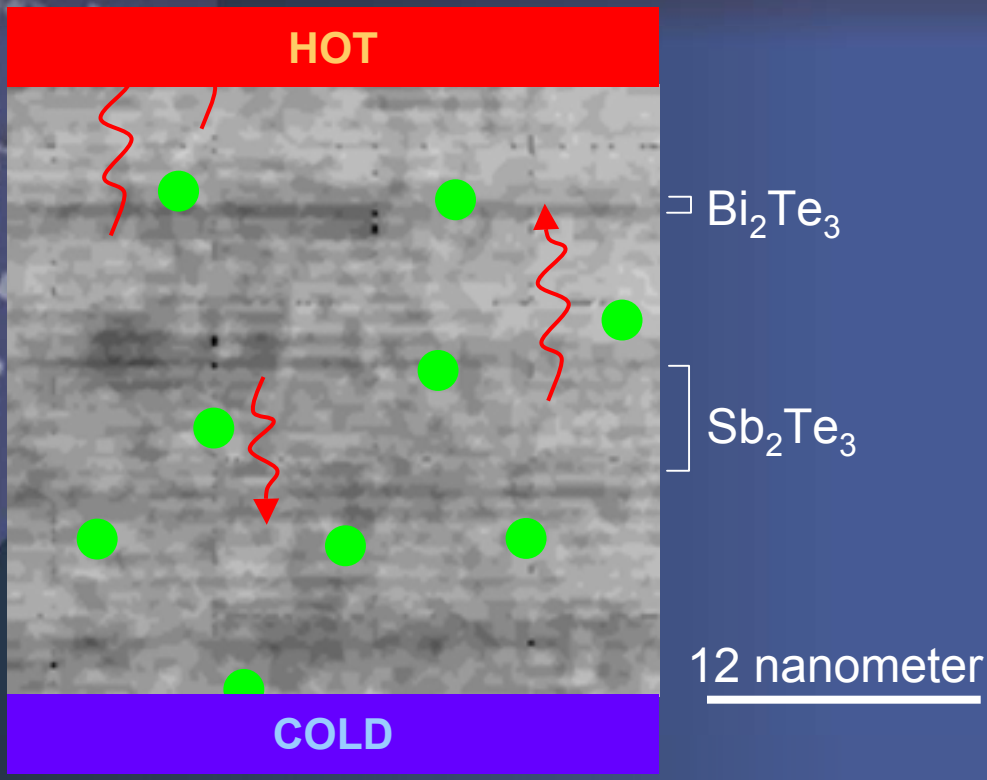

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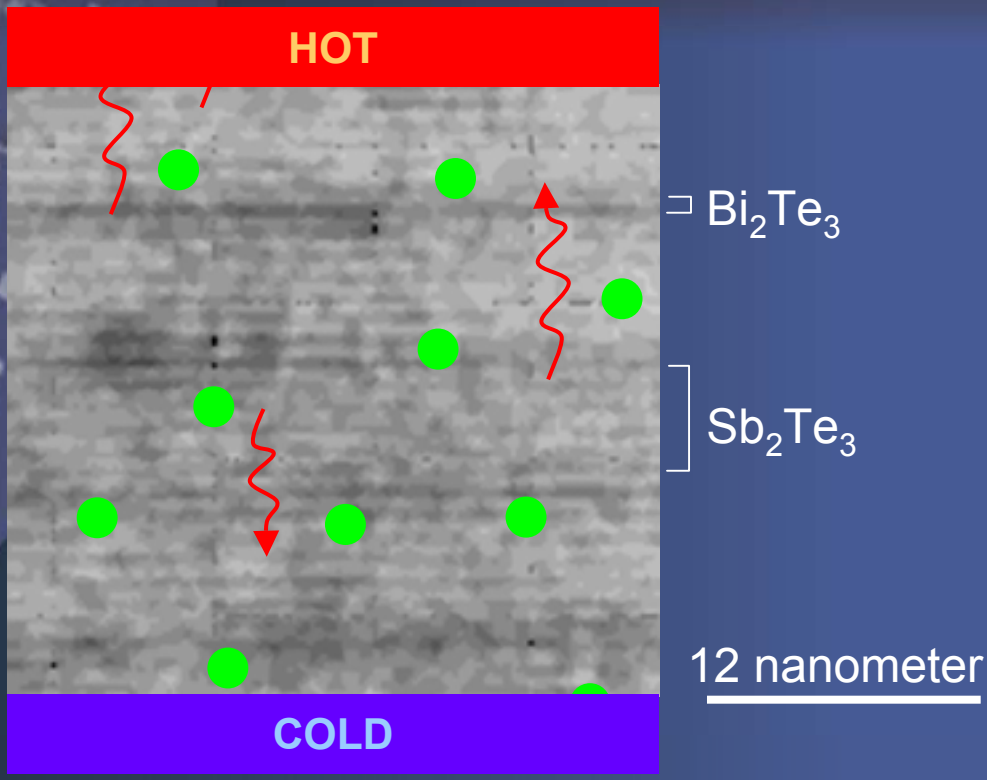

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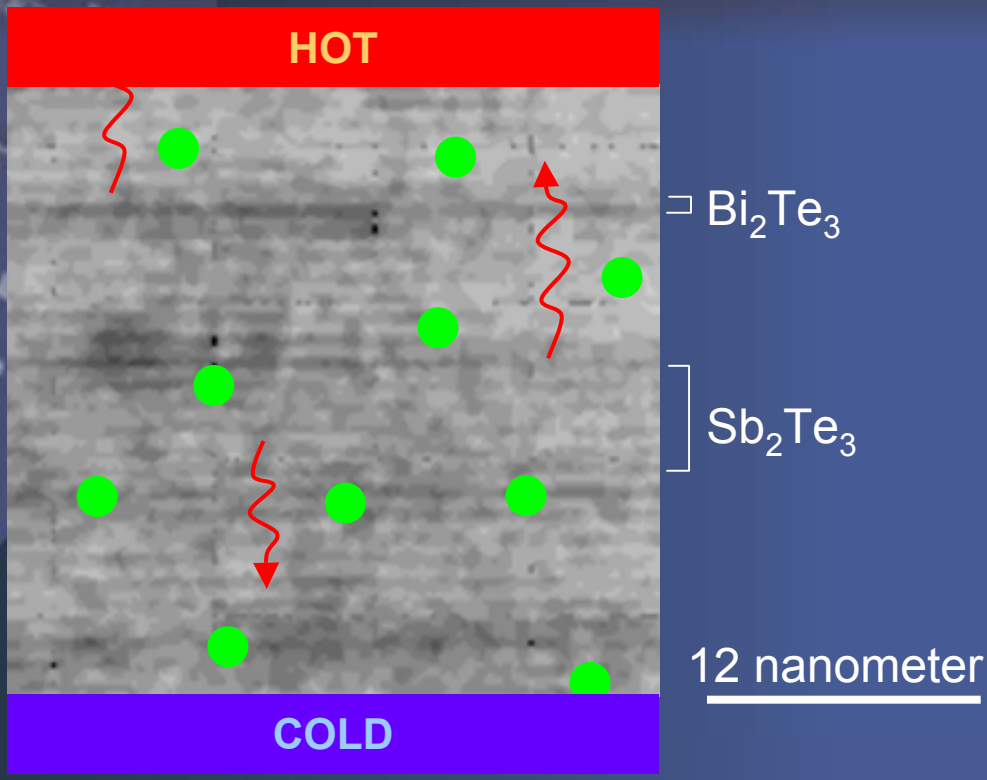

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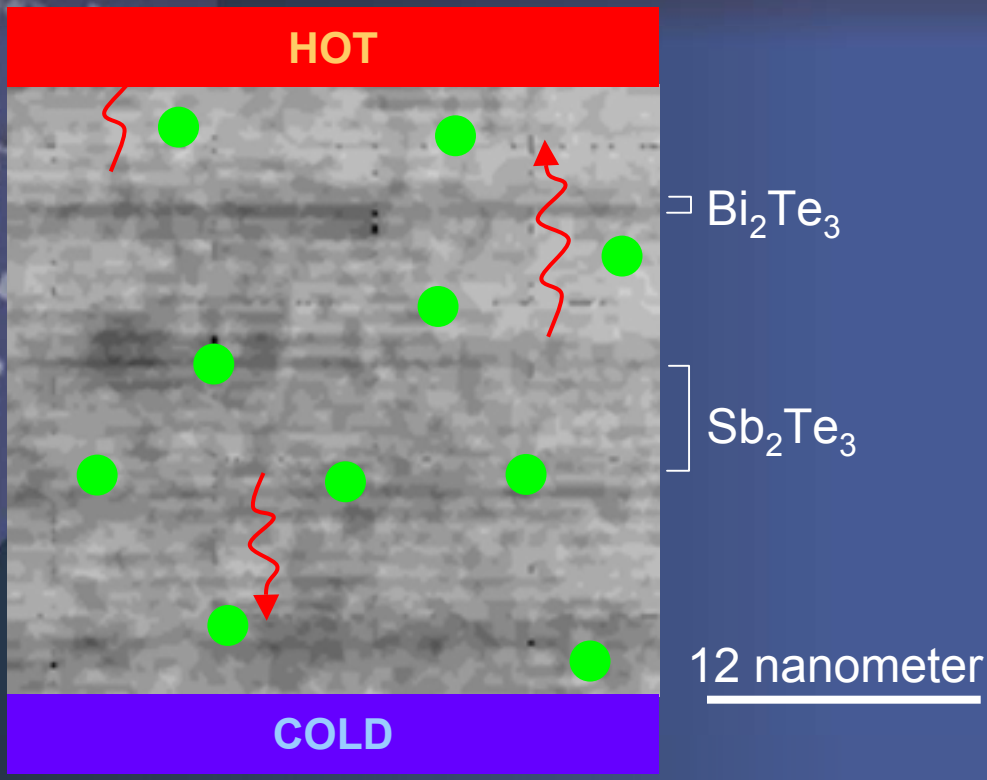

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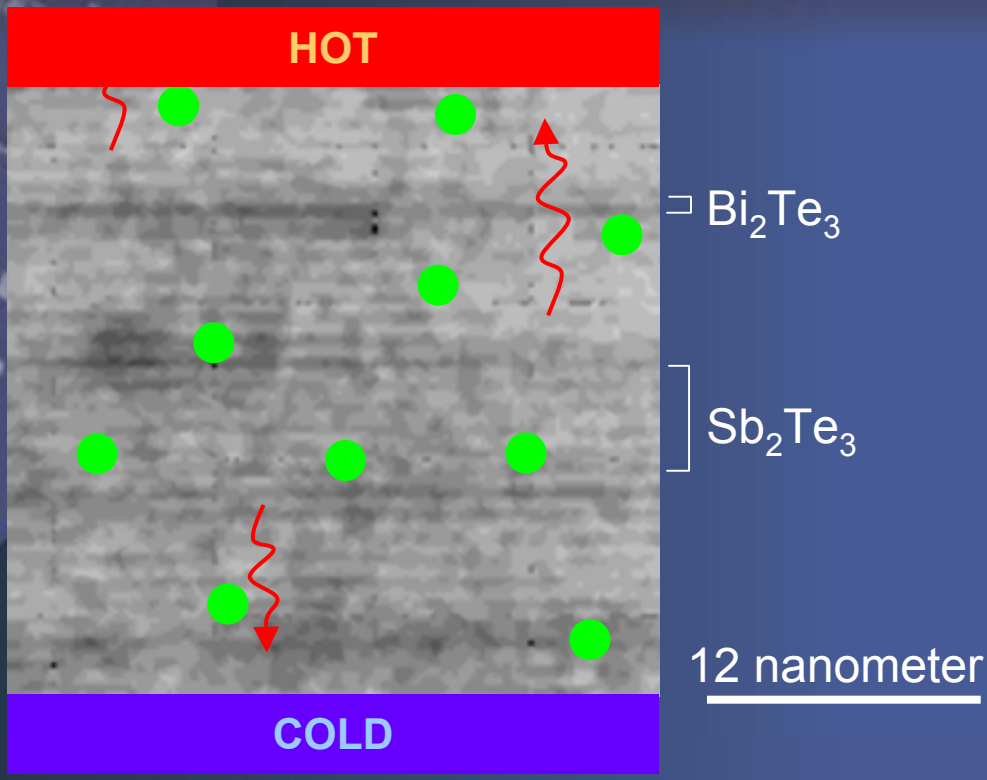

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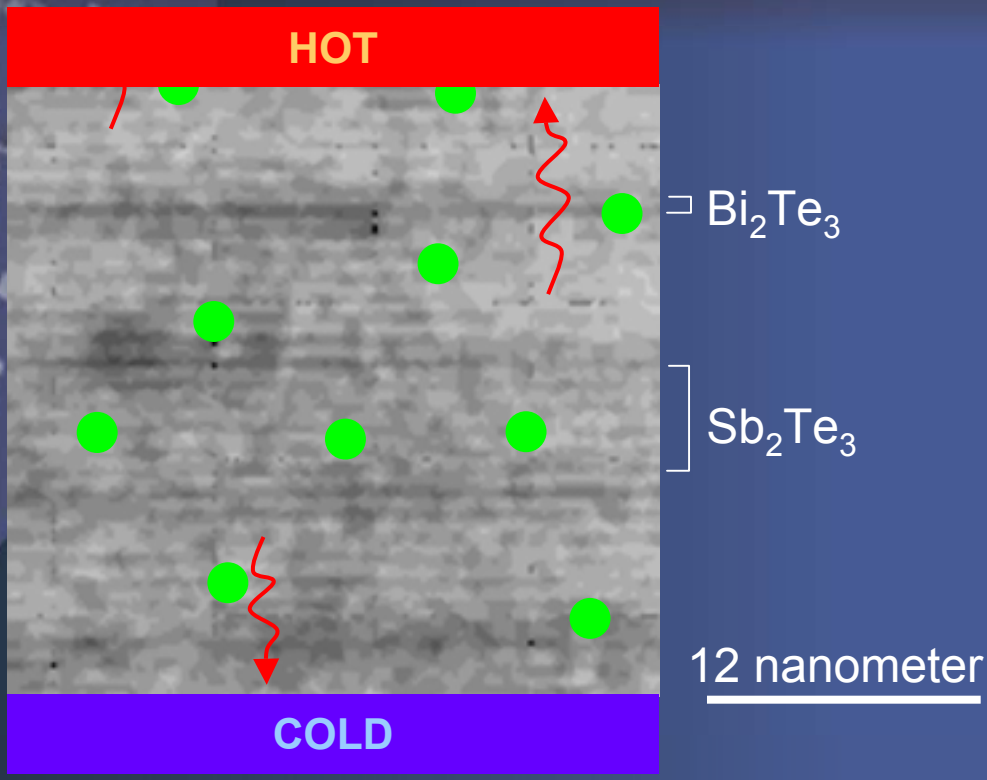

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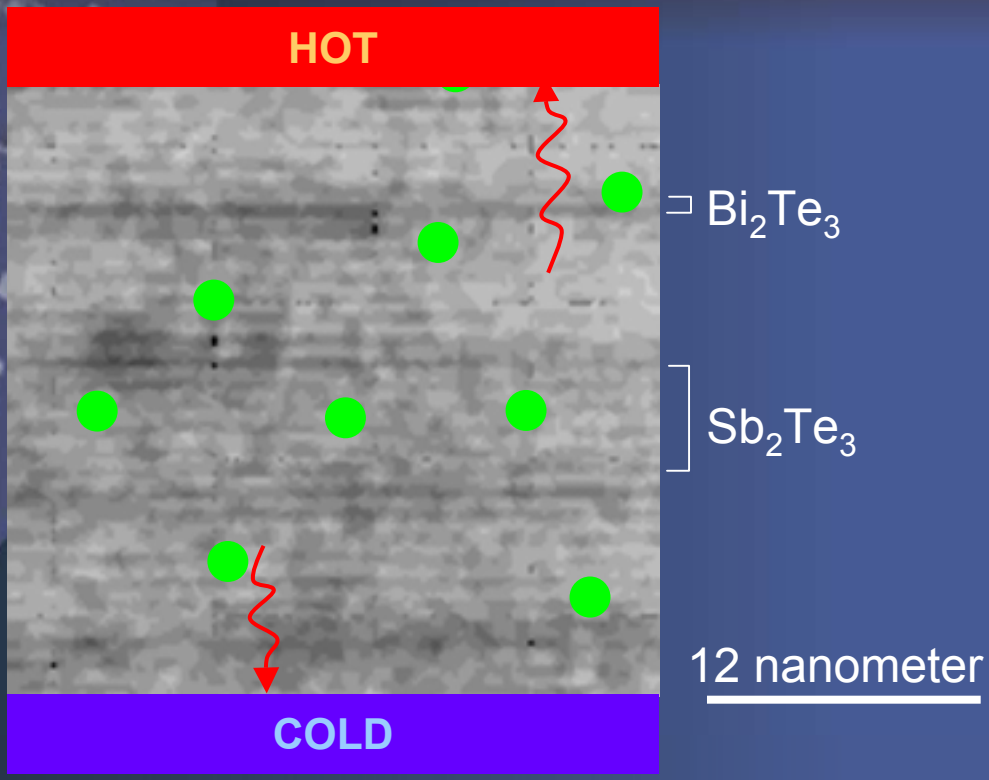

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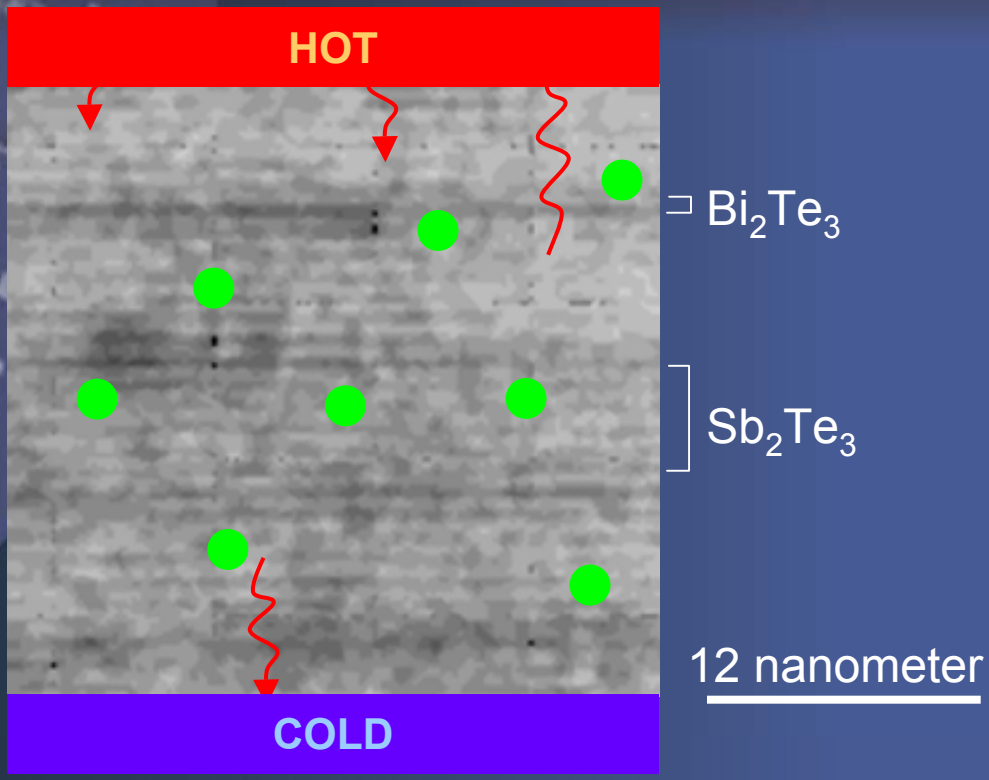

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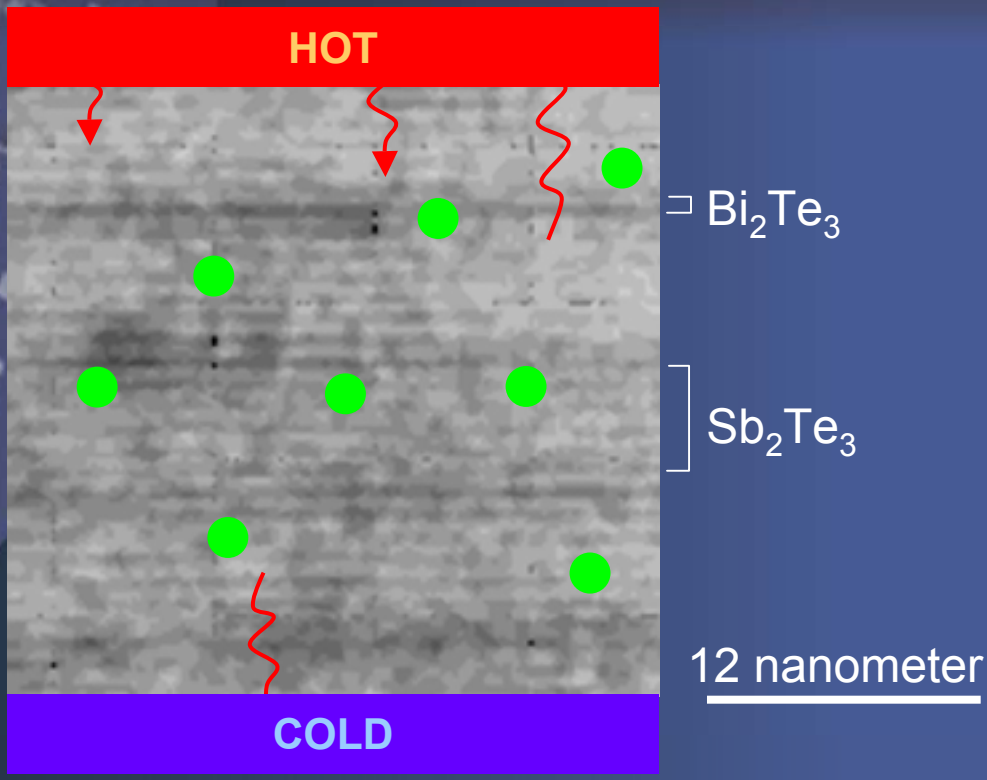

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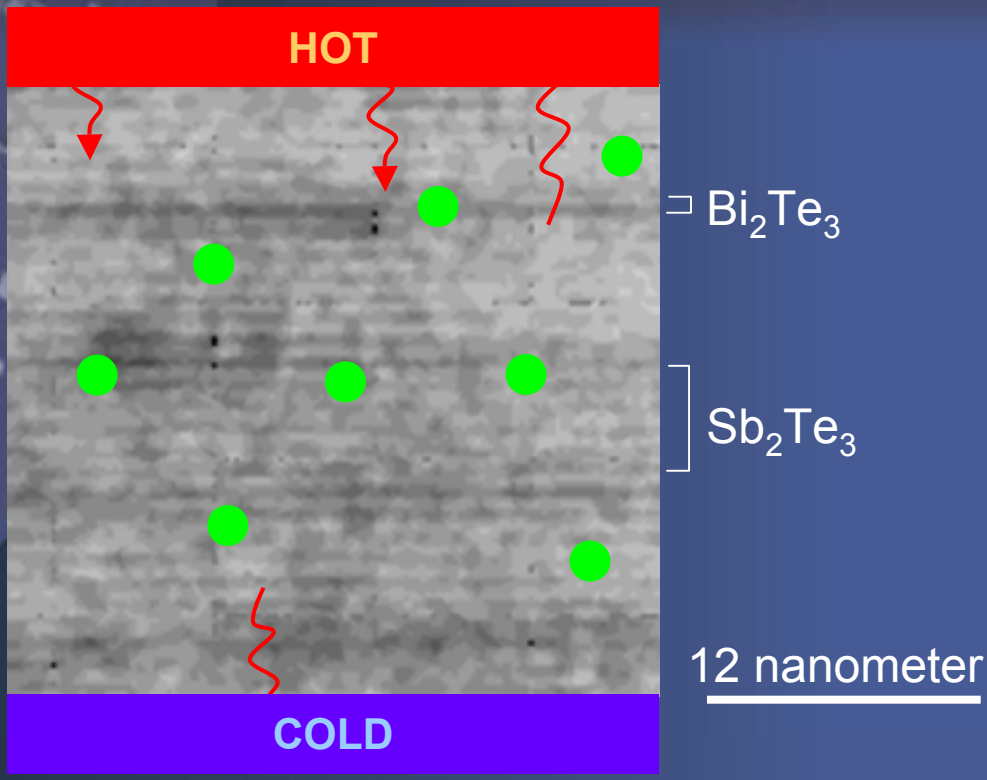

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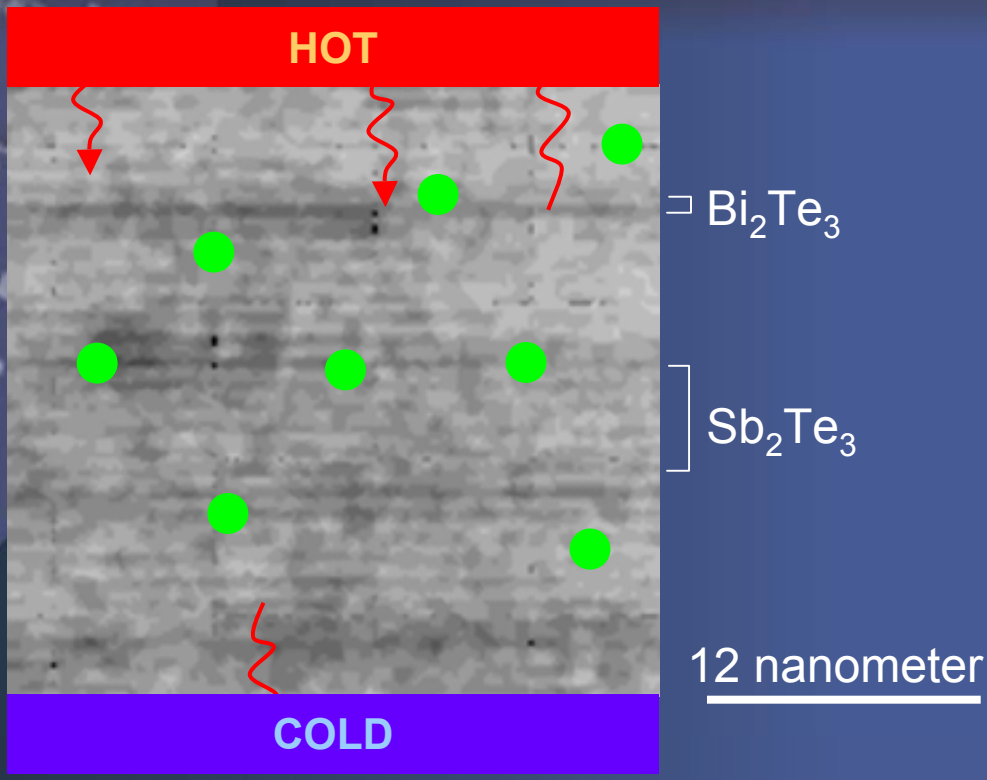

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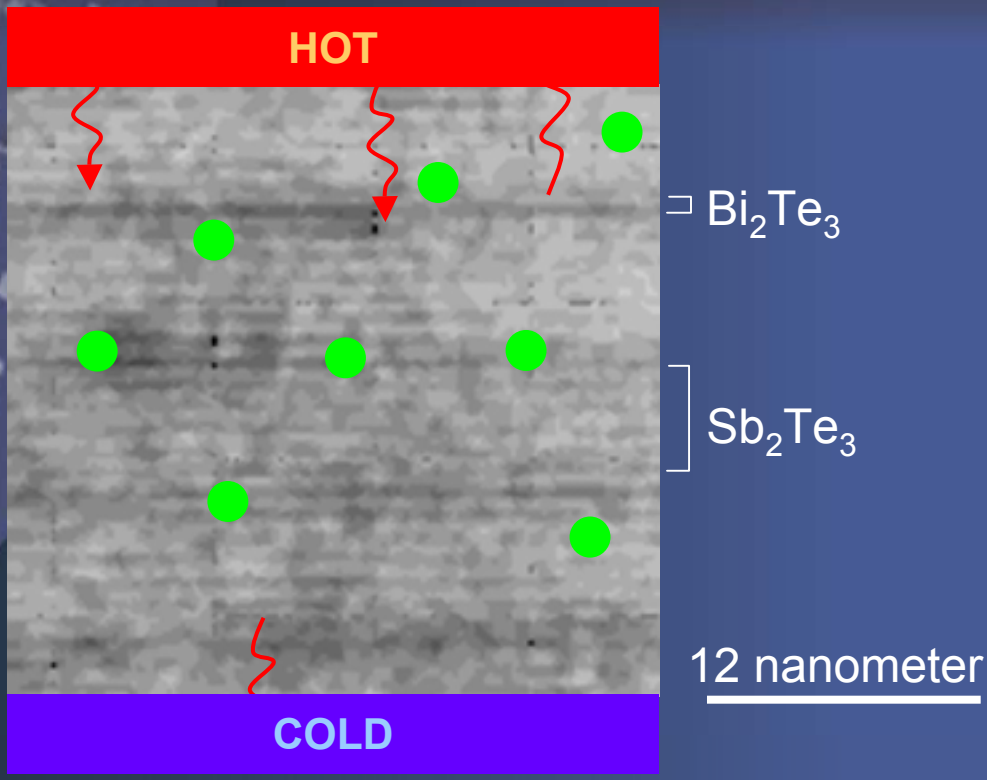

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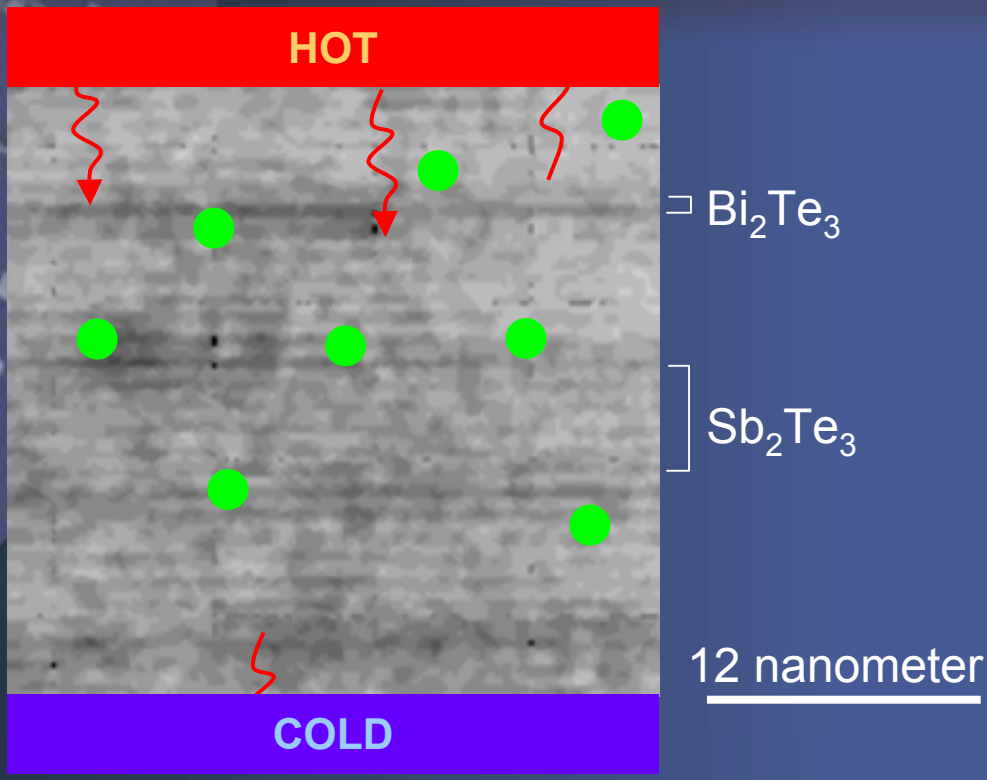

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